US 20140355428A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2014/0355428 A1**

(43) **Pub. Date: Dec. 4, 2014**

Smith et al.

(54) **METHODS AND SYSTEM FOR DYNAMIC SPECTRUM ARBITRAGE POLICY DRIVEN QUALITY OF SERVICE**

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(21) Appl. No.: **14/287,088**

(22) Filed: **May 26, 2014**

Related U.S. Application Data

(60) Provisional application No. 61/827,937, filed on May 28, 2013.

Publication Classification

(51) **Int. Cl.**

H04W 48/06 (2006.01)

H04L 12/24 (2006.01)

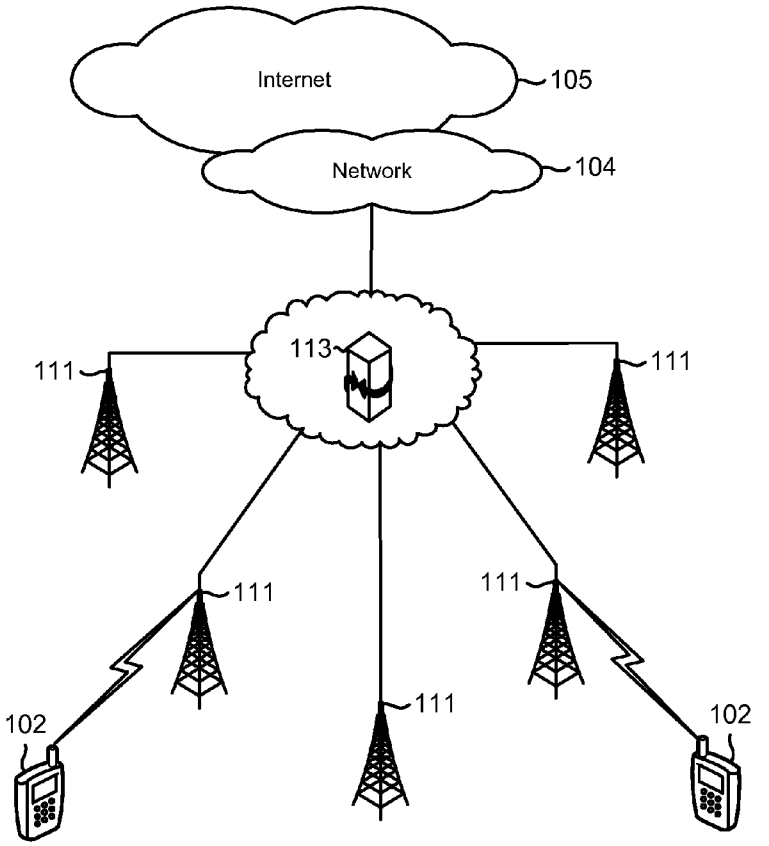
(52) **U.S. Cl.**

CPC ***H04W 48/06*** (2013.01); ***H04L 41/0893*** (2013.01)

USPC **370/230**

(57) **ABSTRACT**

A dynamic spectrum arbitrage (DSA) system includes a dynamic spectrum policy controller (DPC) and a dynamic spectrum controller (DSC) that together dynamically manage the allocation and use of resources (e.g., spectrum resources) across different networks. The DSC component may include wired or wireless connections to eNodeBs, a policy and charging rules function (PCRF) component/server, and various other network components. The PCRF may be configured to receive eNodeB congestion state information from the eNodeB, information identifying wireless devices attached to the eNodeB, categorize each of the identified wireless devices into a category selected from a plurality of categories, select a subset of the identified wireless devices based on the category into which they are categorized, and perform congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB.



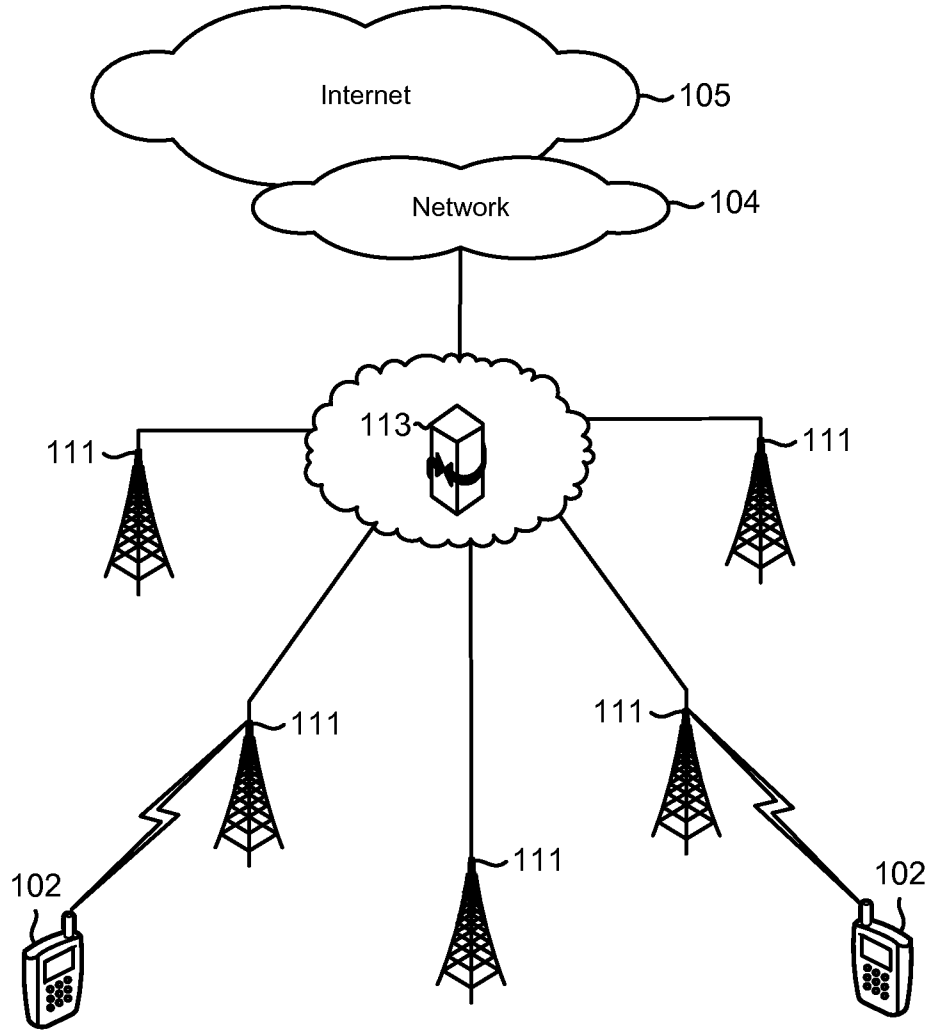


FIG. 1A

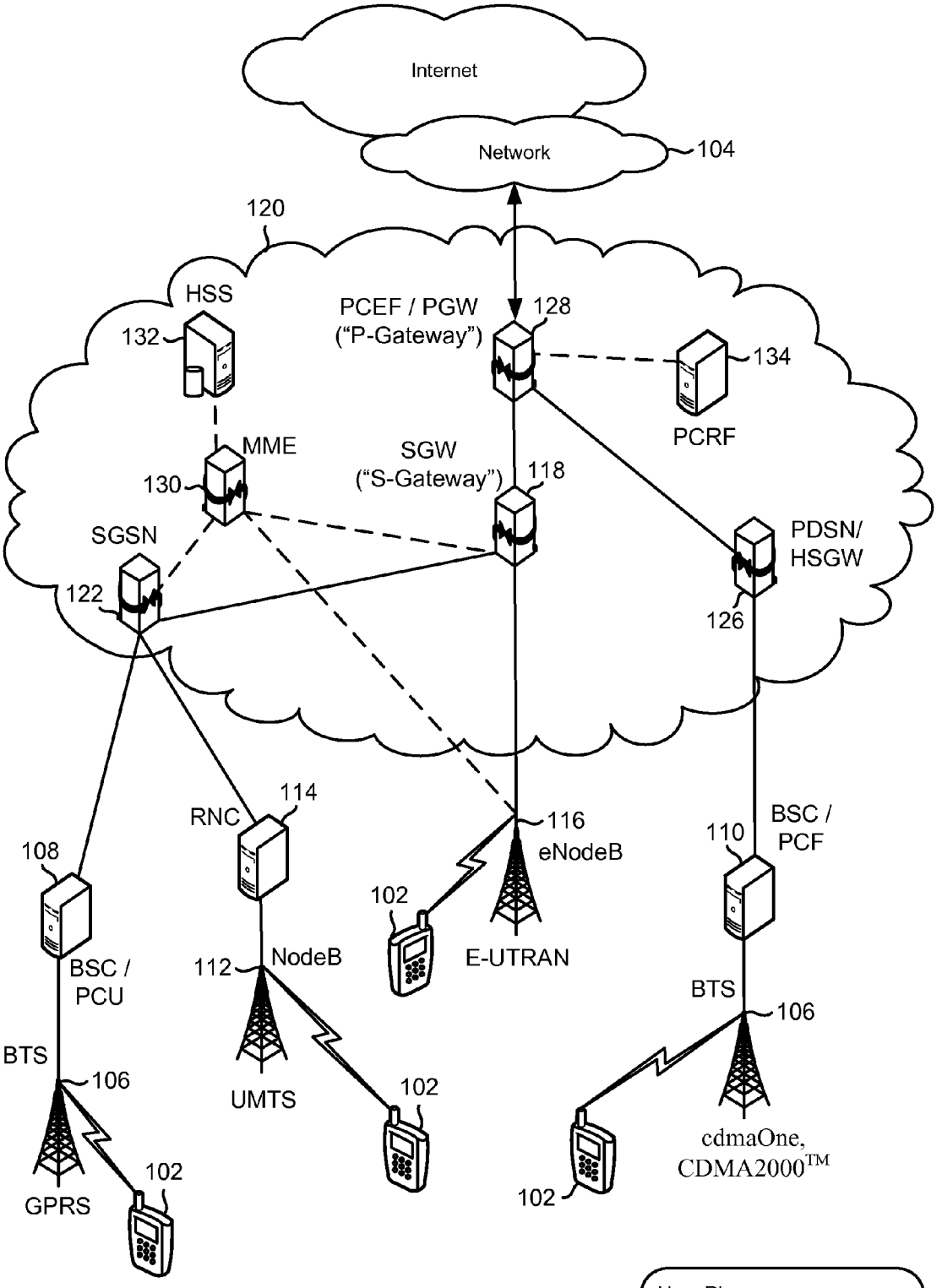

Internet
Network
104
120
HSS
132
PCEF / PGW
("P-Gateway")
128
134
PCRF
MME
130
SGW
("S-Gateway")
118
SGSN
122
PDSN/
HSGW
126
114
RNC
116
eNodeB
108
102
BSC /
PCU
112
NodeB
E-UTRAN
110
BSC /
PCF
BTS
106
BTS
106
UMTS
102
102
GPRS
102
cdmaOne,
CDMA2000™
102
User Plane
Control Plane

FIG. 1B

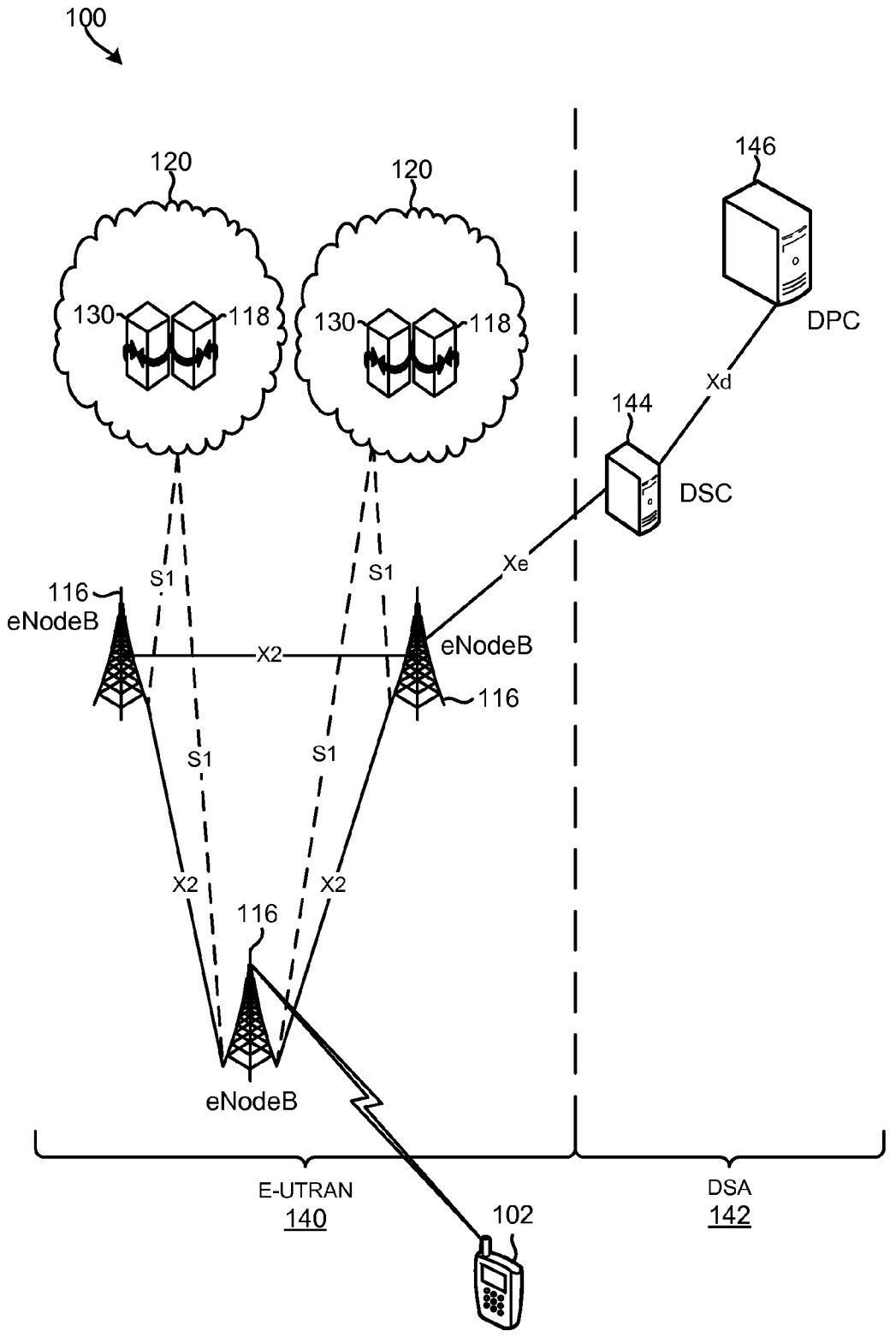

100
120
120
146
130
118
130
118
DPC
Xd
144
DSC
Xe
S1
S1
116
eNodeB
X2
eNodeB
116
S1
S1
X2
X2
116
eNodeB
E-UTRAN
140
DSA
142
102

FIG. 1C

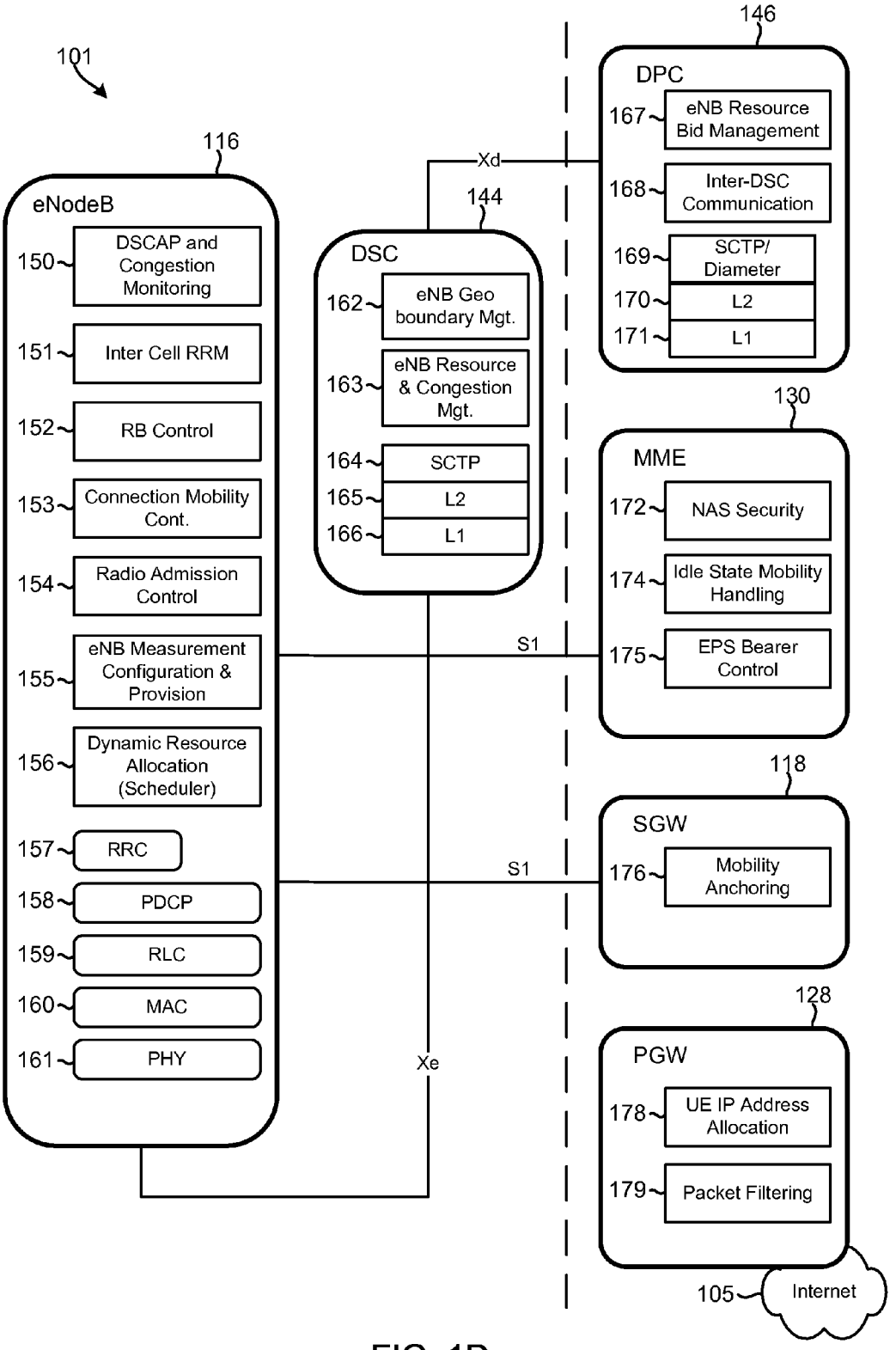

101
116
eNodeB
150
DSCAP and Congestion Monitoring
151
Inter Cell RRM
152
RB Control
153
Connection Mobility Cont.
154
Radio Admission Control
155
eNB Measurement Configuration & Provision
156
Dynamic Resource Allocation (Scheduler)
157
RRC
158
PDCP
159
RLC
160
MAC
161
PHY
144
DSC
162
eNB Geo boundary Mgt.
163
eNB Resource & Congestion Mgt.
164
SCTP
165
L2
166
L1
Xd
Xe
S1
S1
146
DPC
167
eNB Resource Bid Management
168
Inter-DSC Communication
169
SCTP/ Diameter
170
L2
171
L1
130
MME
172
NAS Security
174
Idle State Mobility Handling
175
EPS Bearer Control
118
SGW
176
Mobility Anchoring
128
PGW
178
UE IP Address Allocation
179
Packet Filtering
105
Internet

FIG. 1D

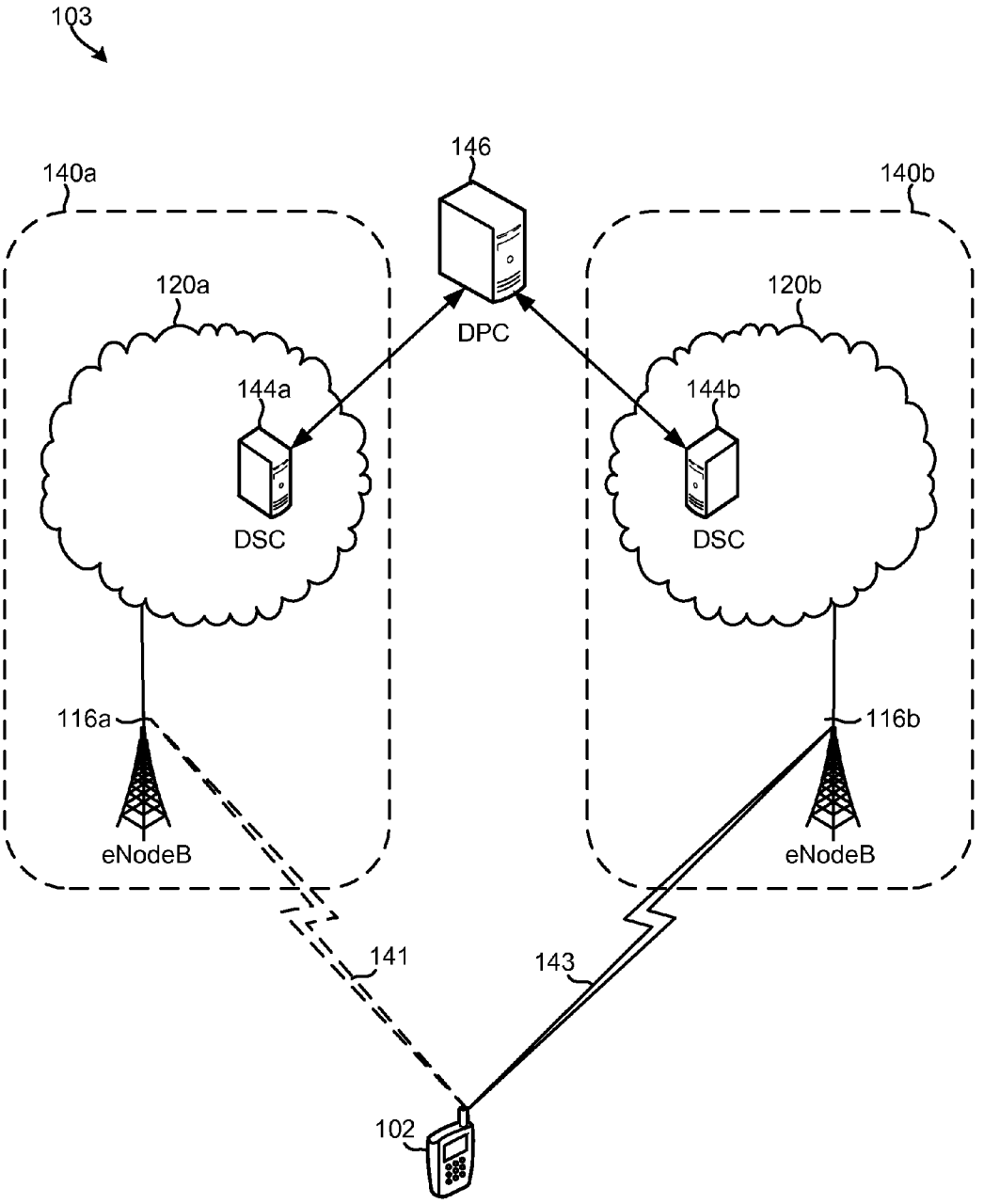

103
146
140a
140b
120a
120b
DPC
144a
144b
DSC
DSC
116a
116b
eNodeB
eNodeB
141
143
102

FIG. 1E

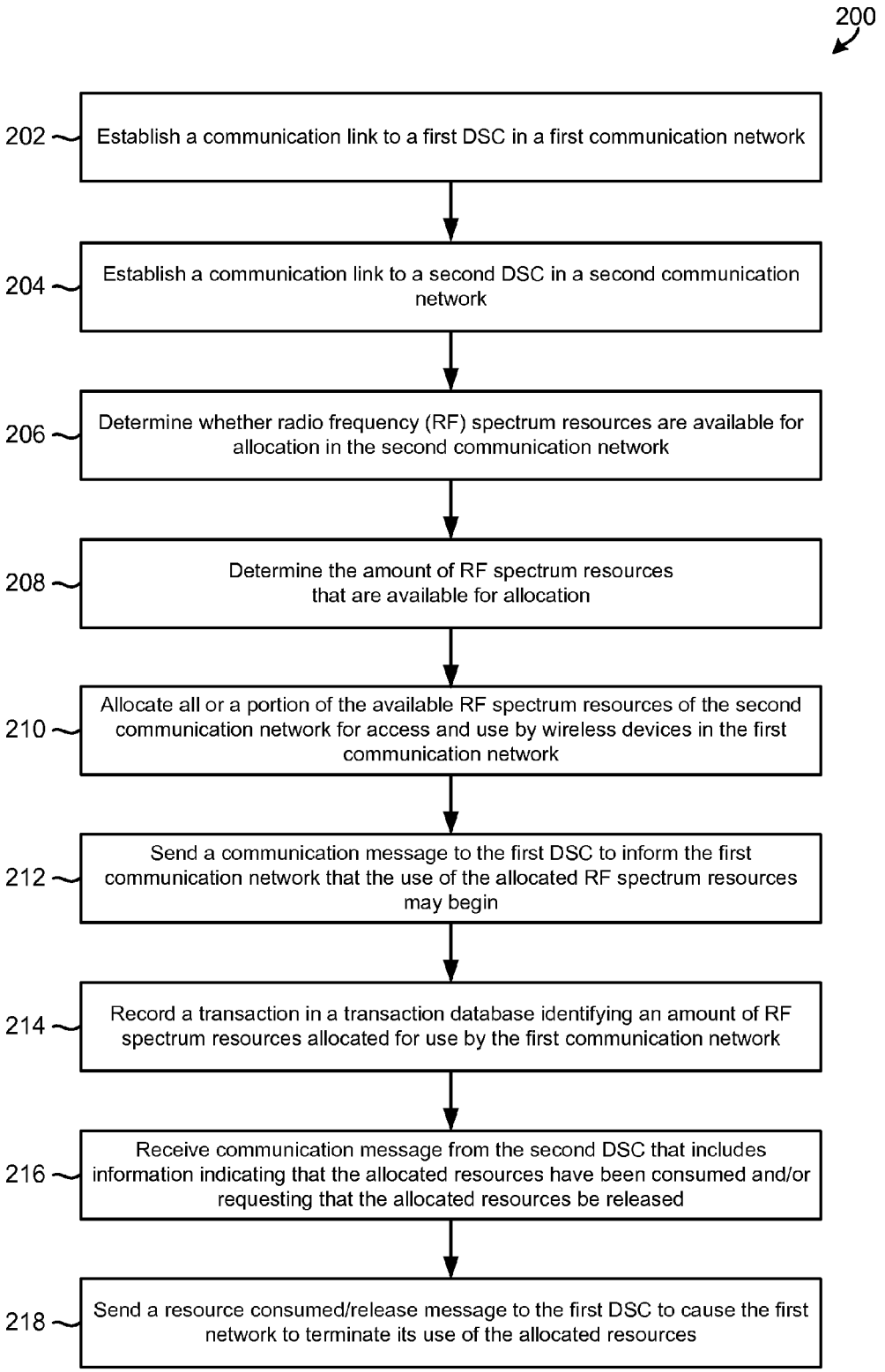

200
202
Establish a communication link to a first DSC in a first communication network
204
Establish a communication link to a second DSC in a second communication network
206
Determine whether radio frequency (RF) spectrum resources are available for allocation in the second communication network
208
Determine the amount of RF spectrum resources that are available for allocation
210
Allocate all or a portion of the available RF spectrum resources of the second communication network for access and use by wireless devices in the first communication network
212
Send a communication message to the first DSC to inform the first communication network that the use of the allocated RF spectrum resources may begin
214
Record a transaction in a transaction database identifying an amount of RF spectrum resources allocated for use by the first communication network
216
Receive communication message from the second DSC that includes information indicating that the allocated resources have been consumed and/or requesting that the allocated resources be released
218
Send a resource consumed/release message to the first DSC to cause the first network to terminate its use of the allocated resources

FIG. 2A

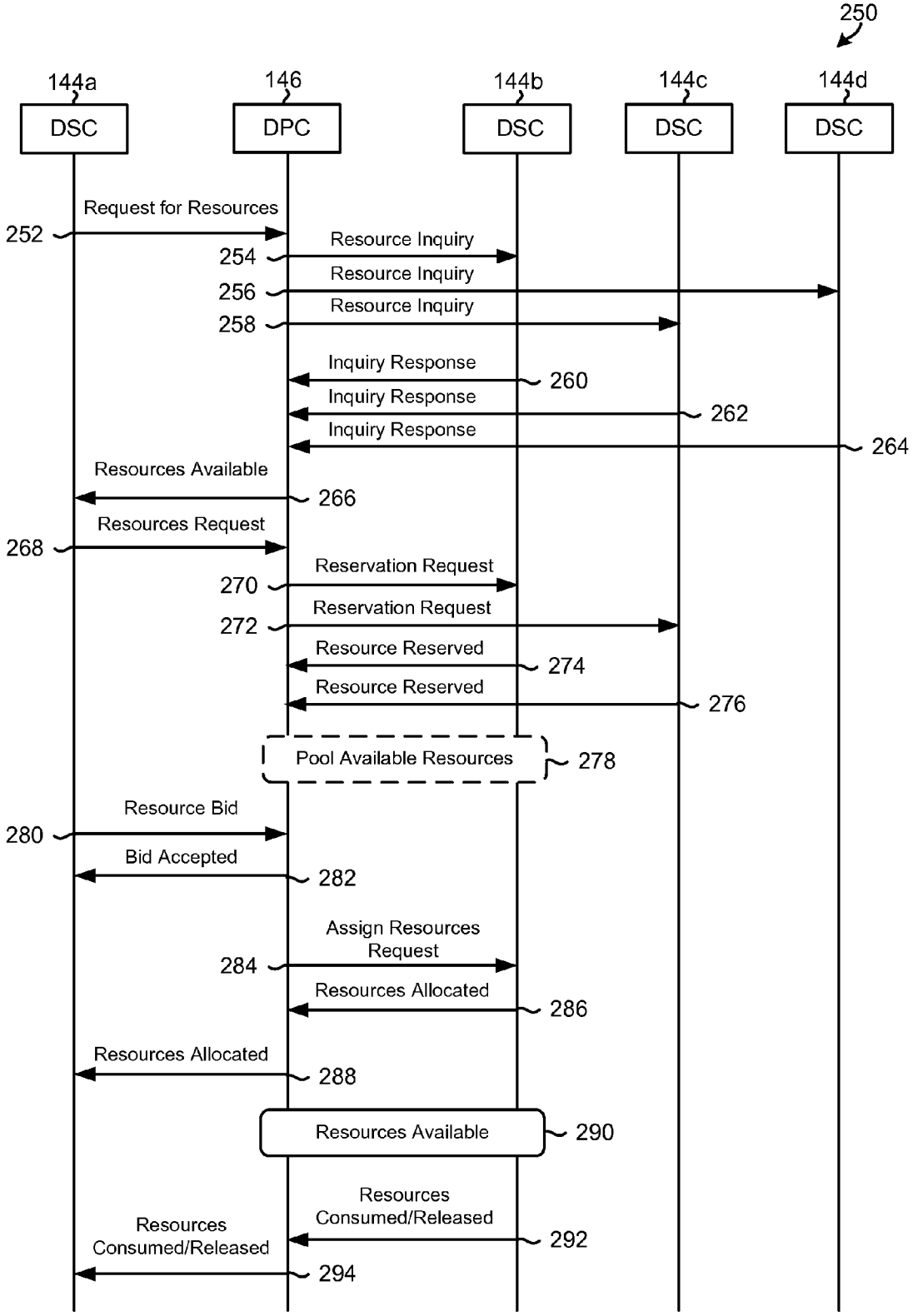

250
144a
DSC
146
DPC
144b
DSC
144c
DSC
144d
DSC
Request for Resources
252
Resource Inquiry
254
Resource Inquiry
256
Resource Inquiry
258
Inquiry Response
260
Inquiry Response
262
Inquiry Response
264
Resources Available
266
Resources Request
268
Reservation Request
270
Reservation Request
272
Resource Reserved
274
Resource Reserved
276
Pool Available Resources
278
Resource Bid
280
Bid Accepted
282
Assign Resources Request
284
Resources Allocated
286
Resources Allocated
288
Resources Available
290
Resources Consumed/Released
292
Resources Consumed/Released
294

FIG. 2B

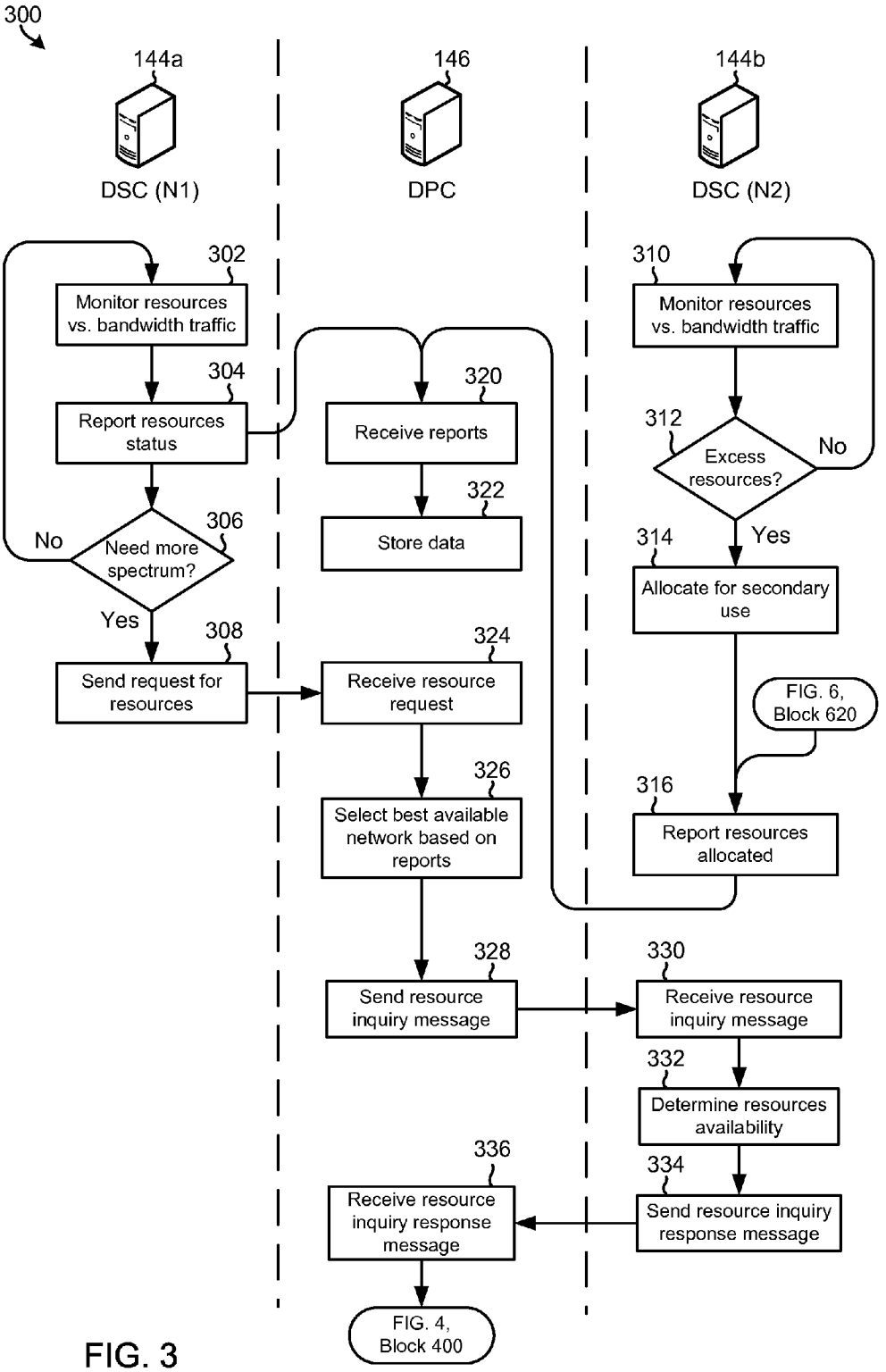

300
144a
DSC (N1)
146
DPC
144b
DSC (N2)
302
Monitor resources vs. bandwidth traffic
304
Report resources status
306
Need more spectrum?
No
Yes
308
Send request for resources
320
Receive reports
322
Store data
324
Receive resource request
326
Select best available network based on reports
328
Send resource inquiry message
336
Receive resource inquiry response message
FIG. 4, Block 400
310
Monitor resources vs. bandwidth traffic
312
Excess resources?
No
Yes
314
Allocate for secondary use
FIG. 6, Block 620
316
Report resources allocated
330
Receive resource inquiry message
332
Determine resources availability
334
Send resource inquiry response message

FIG. 3

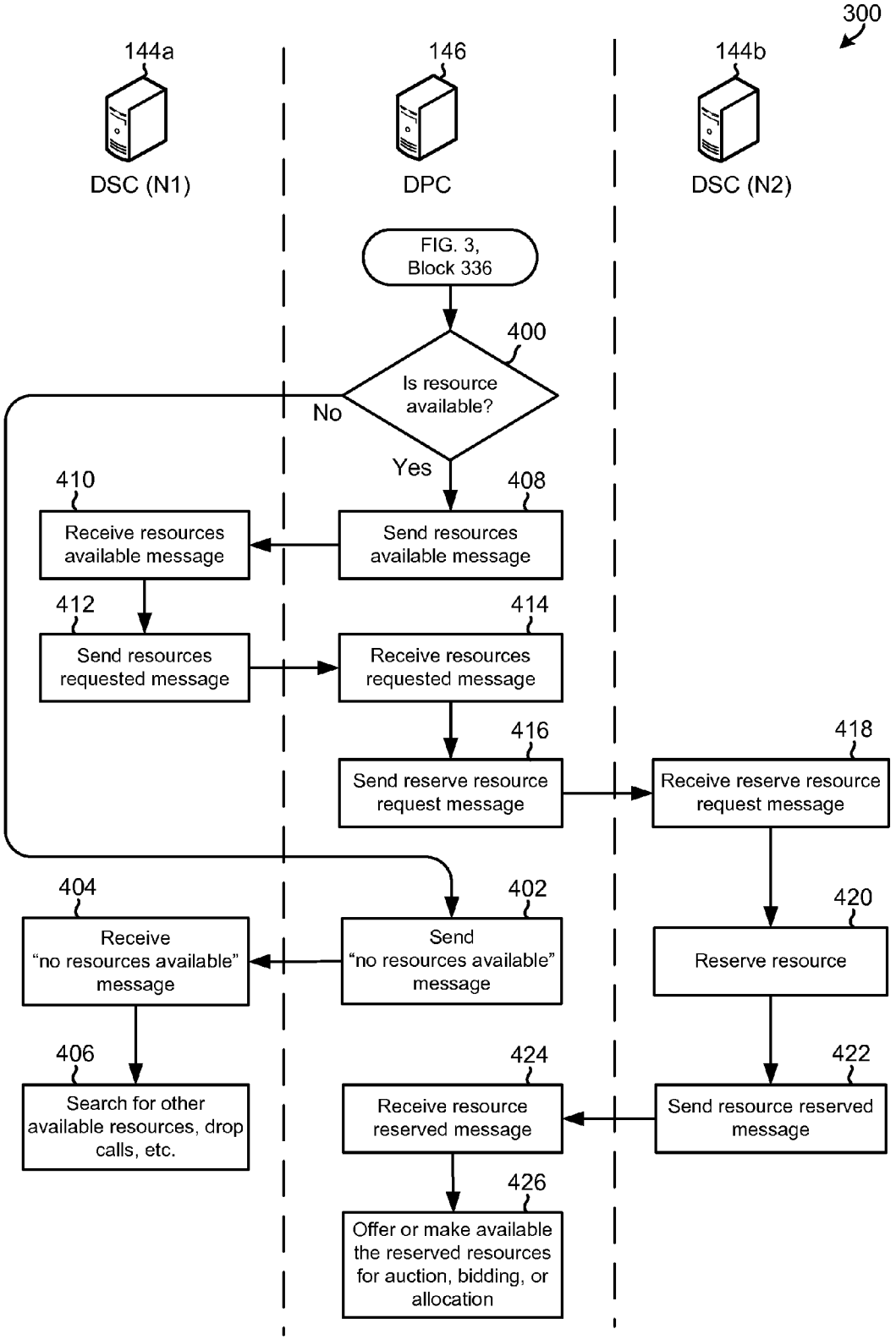

300
144a
146
144b
DSC (N1)
DPC
DSC (N2)
FIG. 3, Block 336
400
Is resource available?
No
Yes
410
Receive resources available message
408
Send resources available message
412
Send resources requested message
414
Receive resources requested message
416
Send reserve resource request message
418
Receive reserve resource request message
404
Receive "no resources available" message
402
Send "no resources available" message
420
Reserve resource
406
Search for other available resources, drop calls, etc.
424
Receive resource reserved message
422
Send resource reserved message
426
Offer or make available the reserved resources for auction, bidding, or allocation

FIG. 4

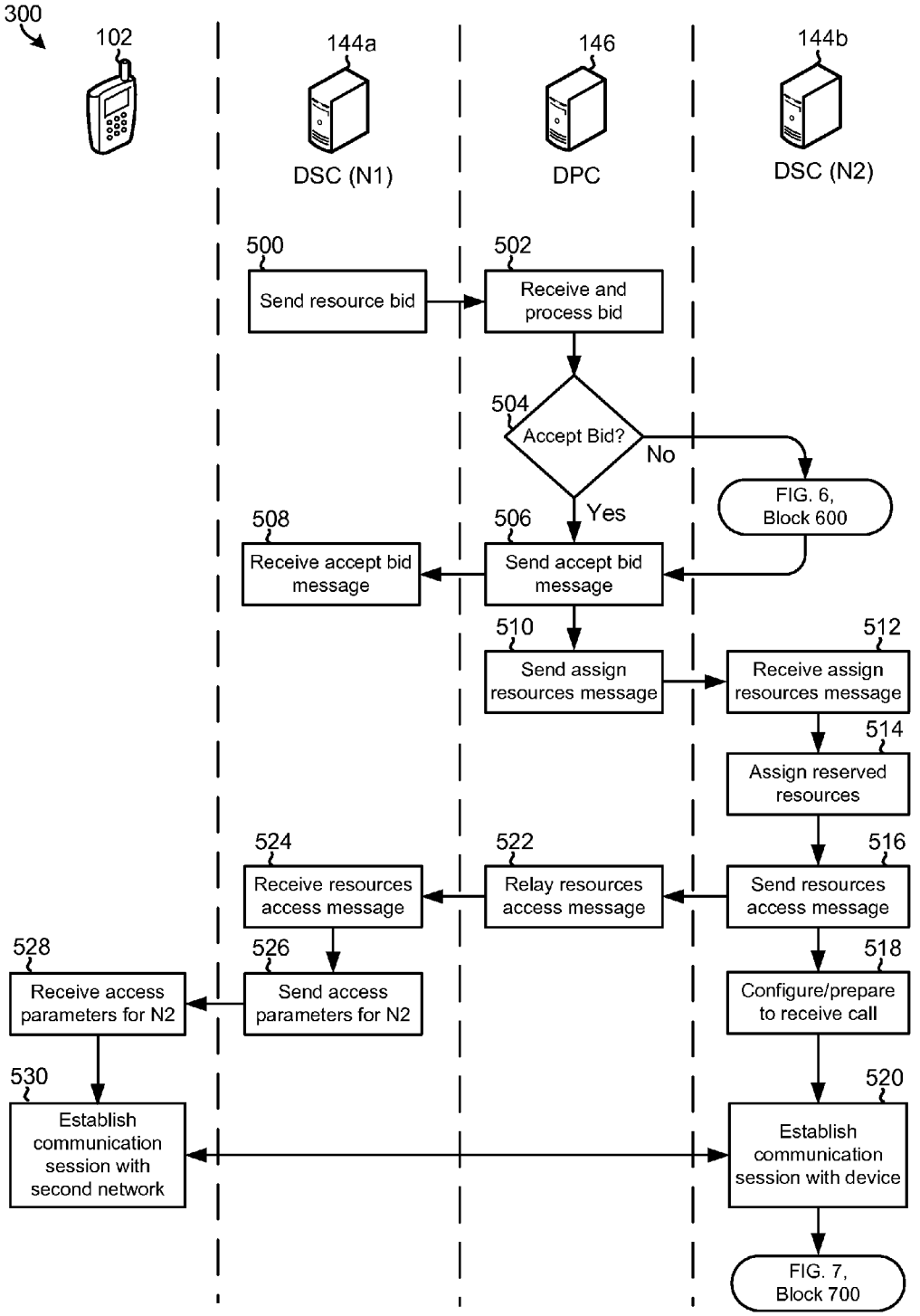

300
102
144a
146
144b
DSC (N1)
DPC
DSC (N2)
500
Send resource bid
502
Receive and process bid
504
Accept Bid?
No
Yes
FIG. 6, Block 600
508
Receive accept bid message
506
Send accept bid message
510
Send assign resources message
512
Receive assign resources message
514
Assign reserved resources
524
Receive resources access message
522
Relay resources access message
516
Send resources access message
528
Receive access parameters for N2
526
Send access parameters for N2
518
Configure/prepare to receive call
530
Establish communication session with second network
520
Establish communication session with device
FIG. 7, Block 700

FIG. 5

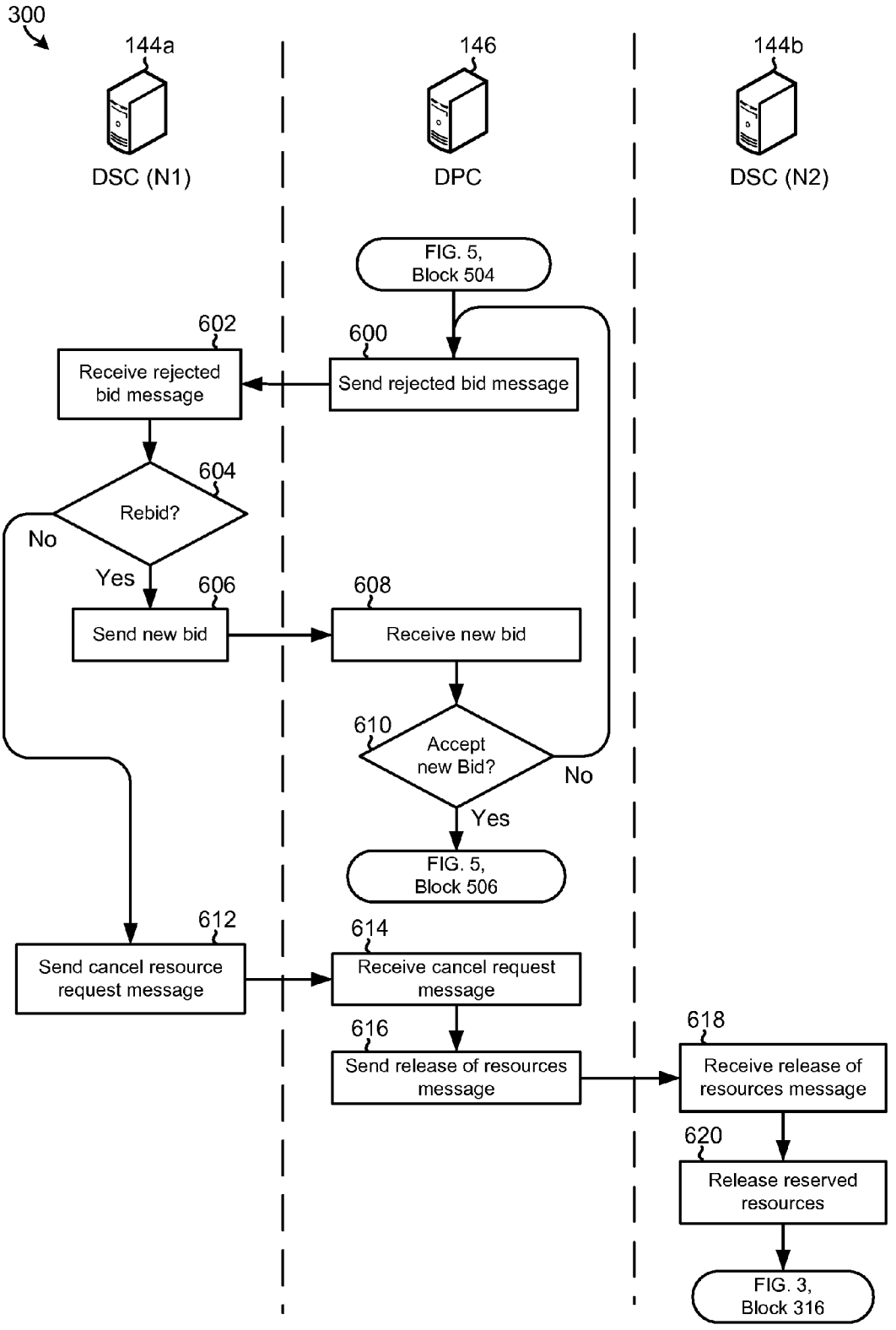

300
144a
146
144b
DSC (N1)
DPC
DSC (N2)
FIG. 5, Block 504
602
600
Receive rejected bid message
Send rejected bid message
604
Rebid?
No
Yes
606
608
Send new bid
Receive new bid
610
Accept new Bid?
No
Yes
FIG. 5, Block 506
612
614
Send cancel resource request message
Receive cancel request message
616
618
Send release of resources message
Receive release of resources message
620
Release reserved resources
FIG. 3, Block 316

FIG. 6

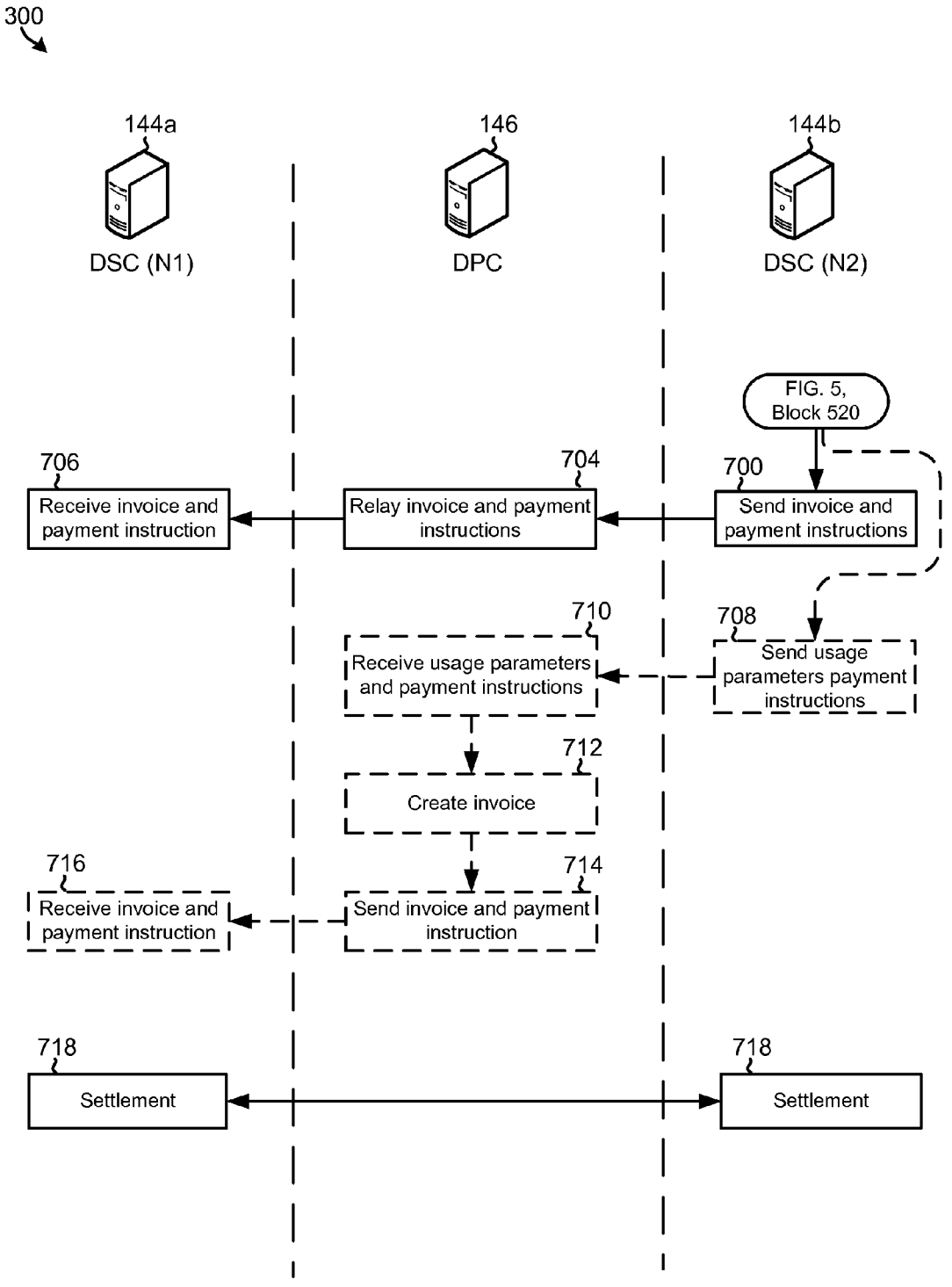

300
144a
146
144b
DSC (N1)
DPC
DSC (N2)
FIG. 5, Block 520
706
Receive invoice and payment instruction
704
Relay invoice and payment instructions
700
Send invoice and payment instructions
710
Receive usage parameters and payment instructions
708
Send usage parameters payment instructions
712
Create invoice
716
Receive invoice and payment instruction
714
Send invoice and payment instruction
718
Settlement
718
Settlement

FIG. 7

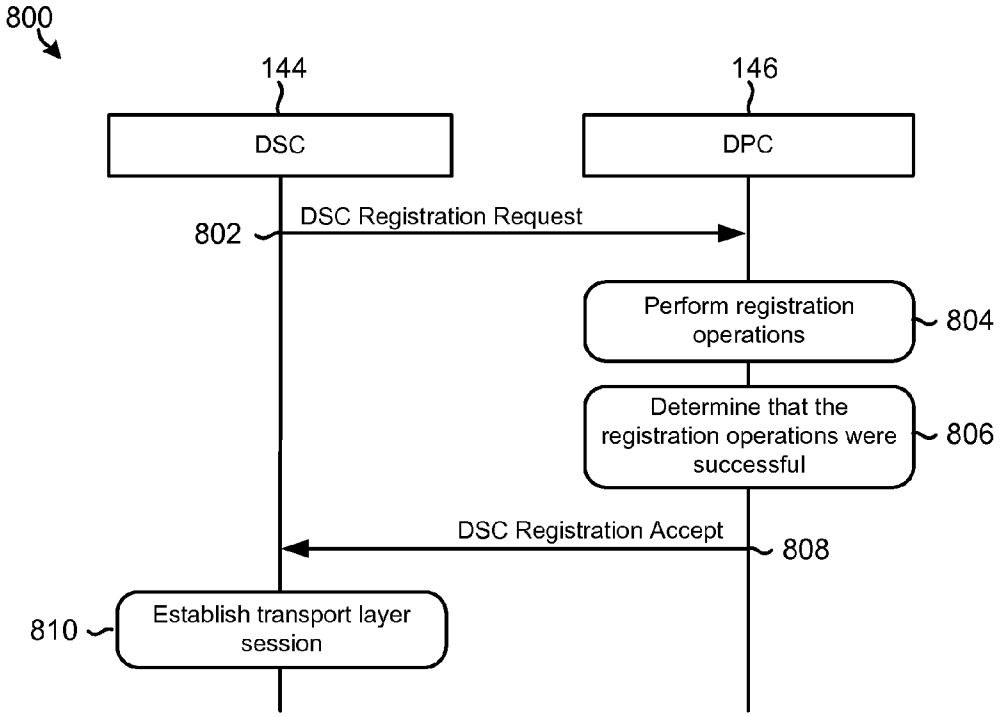

800
144
146
DSC
DPC
802
DSC Registration Request
Perform registration operations
804
Determine that the registration operations were successful
806
DSC Registration Accept
808
810
Establish transport layer session

FIG. 8A

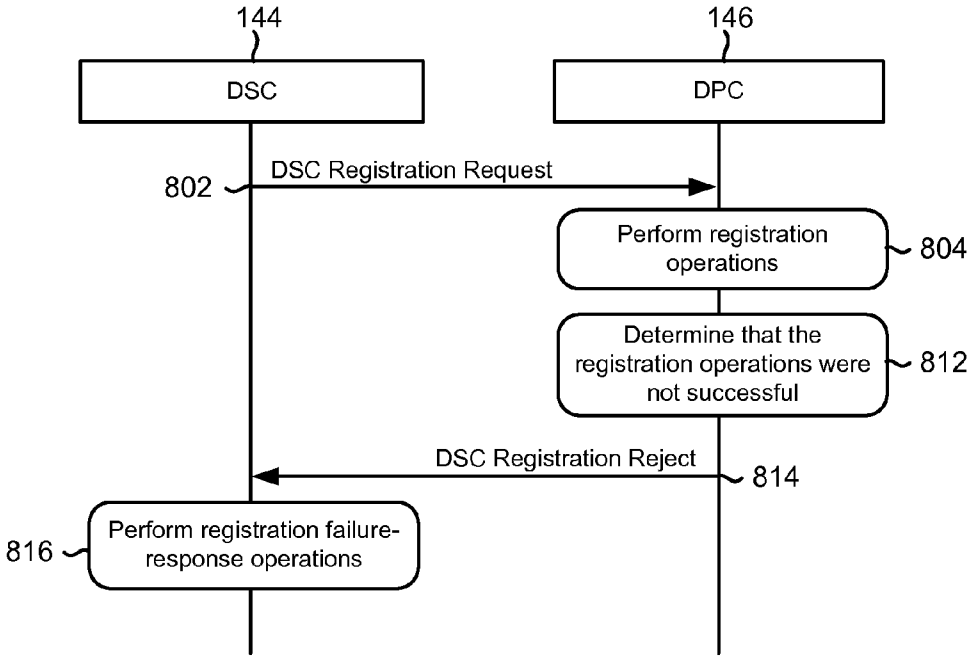

144
146
DSC
DPC
802
DSC Registration Request
Perform registration operations
804
Determine that the registration operations were not successful
812
DSC Registration Reject
814
816
Perform registration failure-response operations

FIG. 8B

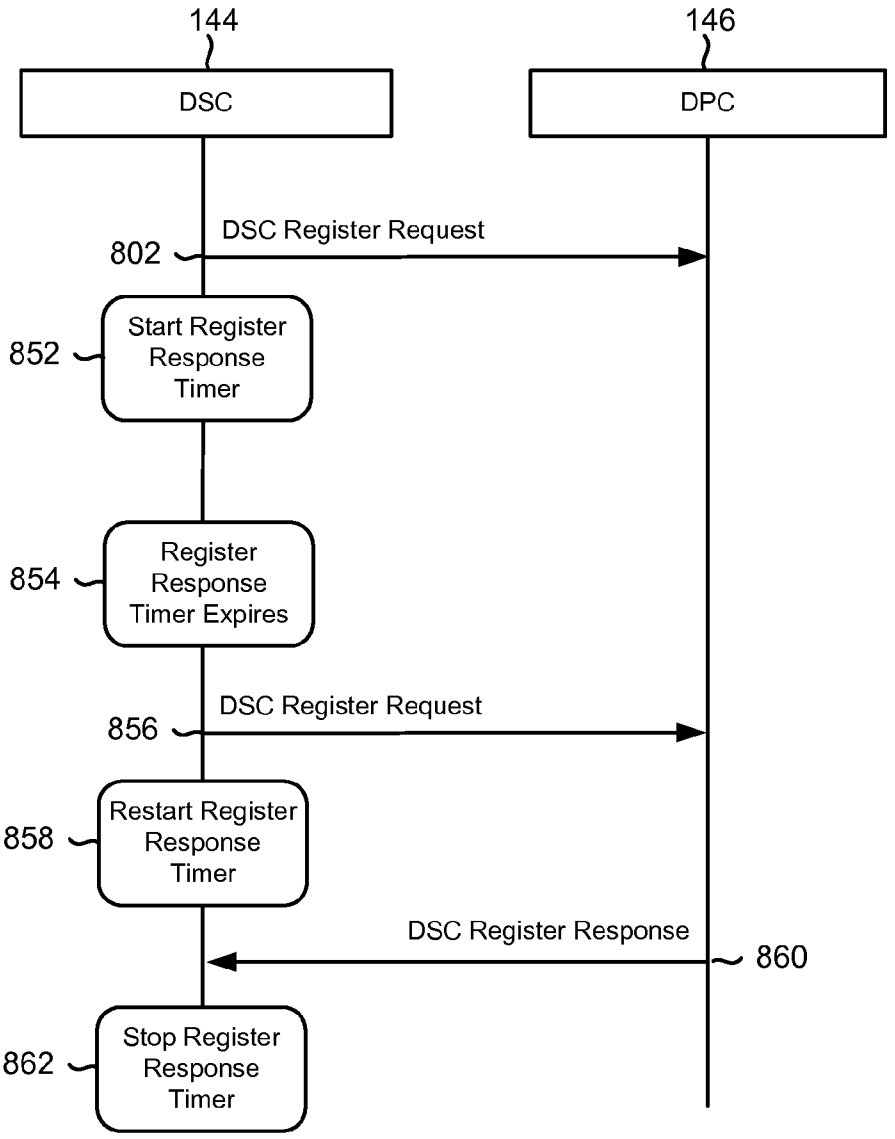

144
146
DSC
DPC
DSC Register Request
802
Start Register Response Timer
852
Register Response Timer Expires
854
DSC Register Request
856
Restart Register Response Timer
858
DSC Register Response
860
Stop Register Response Timer
862

FIG. 8C

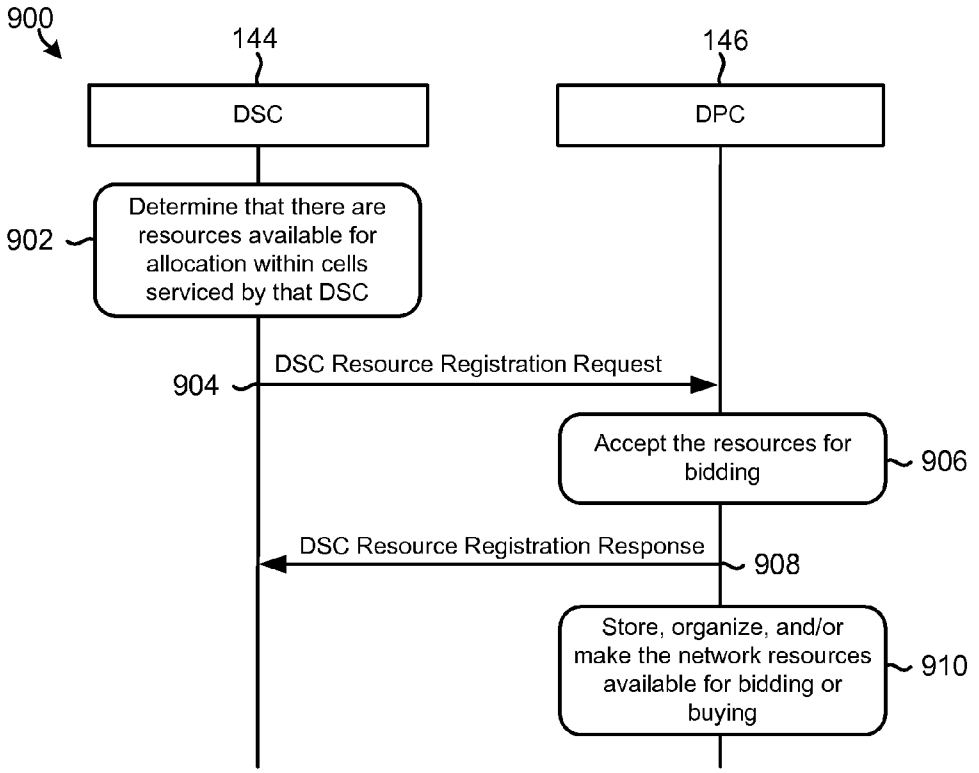

900
144
146
DSC
DPC
Determine that there are resources available for allocation within cells serviced by that DSC
902
DSC Resource Registration Request
904
Accept the resources for bidding
906
DSC Resource Registration Response
908
Store, organize, and/or make the network resources available for bidding or buying
910

FIG. 9A

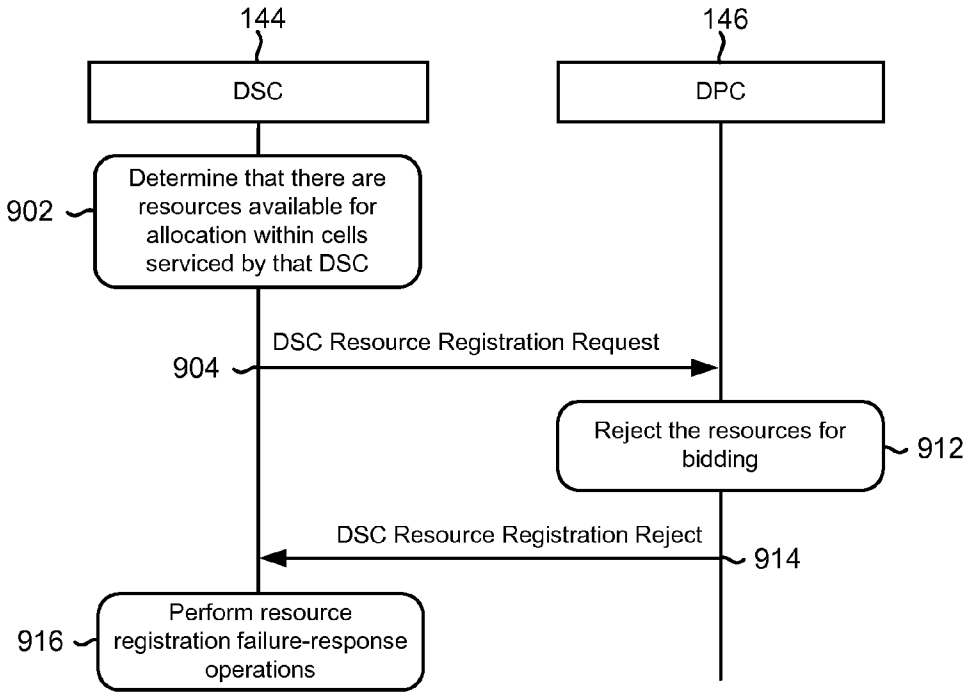

144
146
DSC
DPC
Determine that there are resources available for allocation within cells serviced by that DSC
902
DSC Resource Registration Request
904
Reject the resources for bidding
912
DSC Resource Registration Reject
914
Perform resource registration failure-response operations
916

FIG. 9B

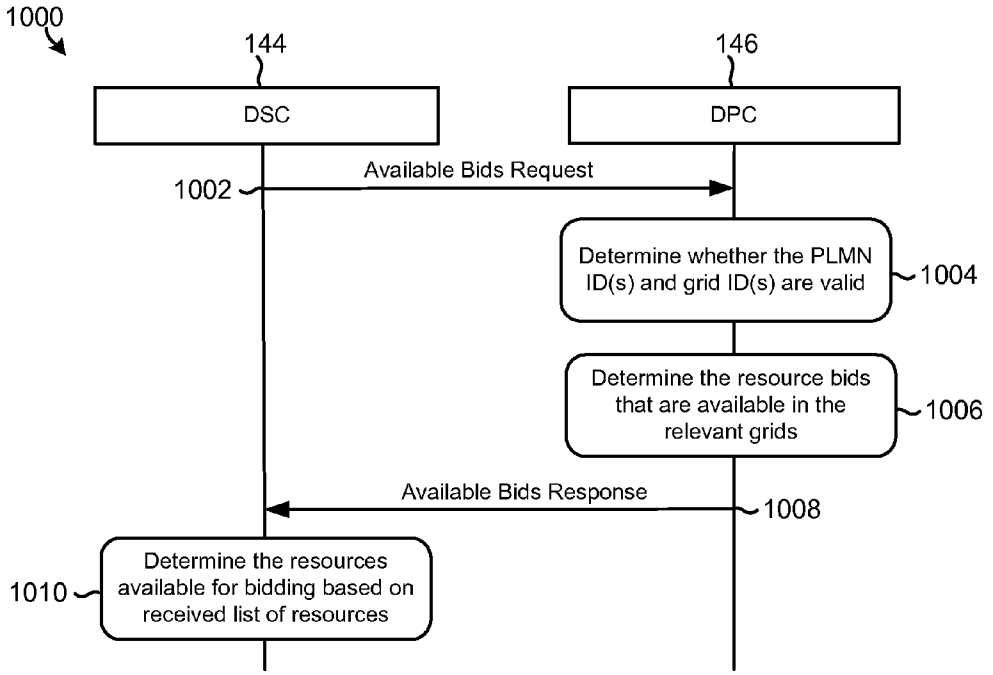


FIG. 10A

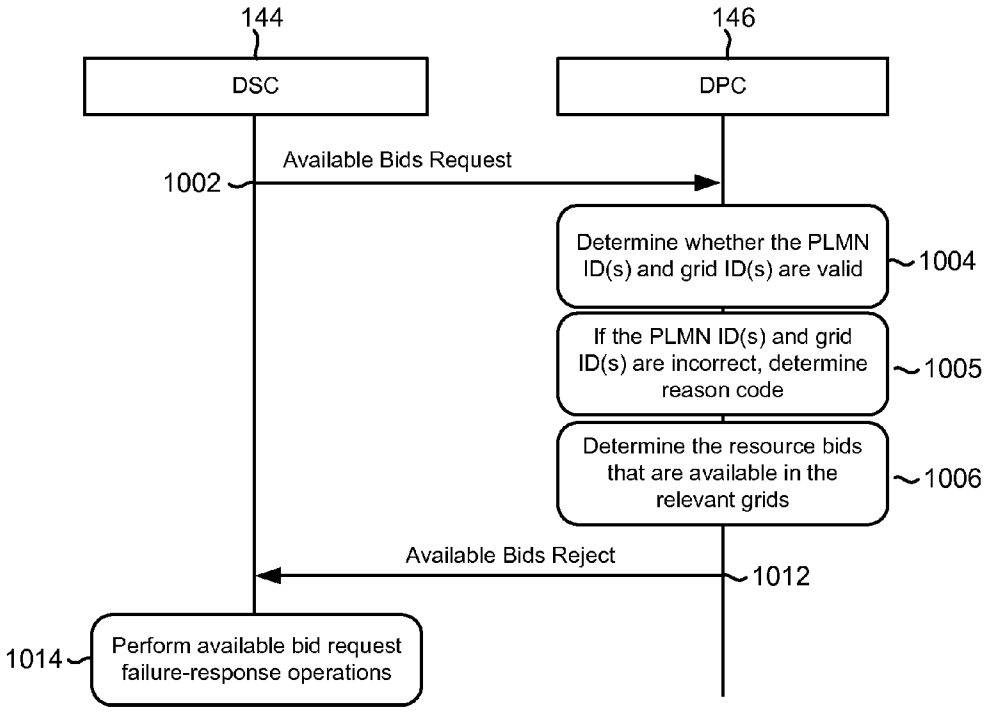


FIG. 10B

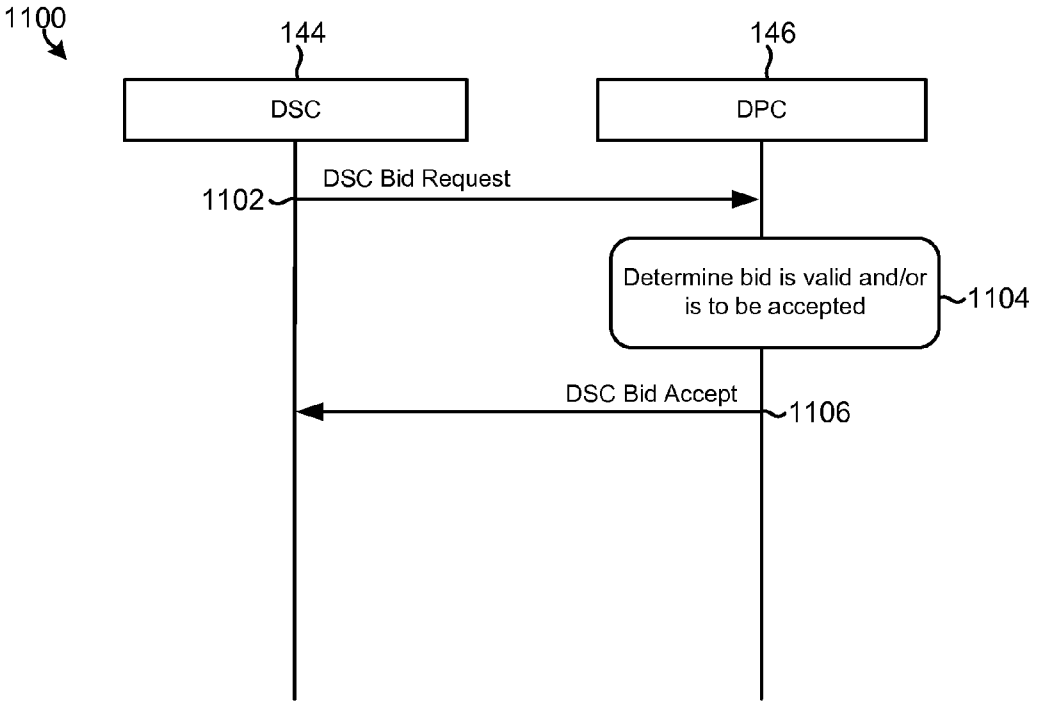


FIG. 11A

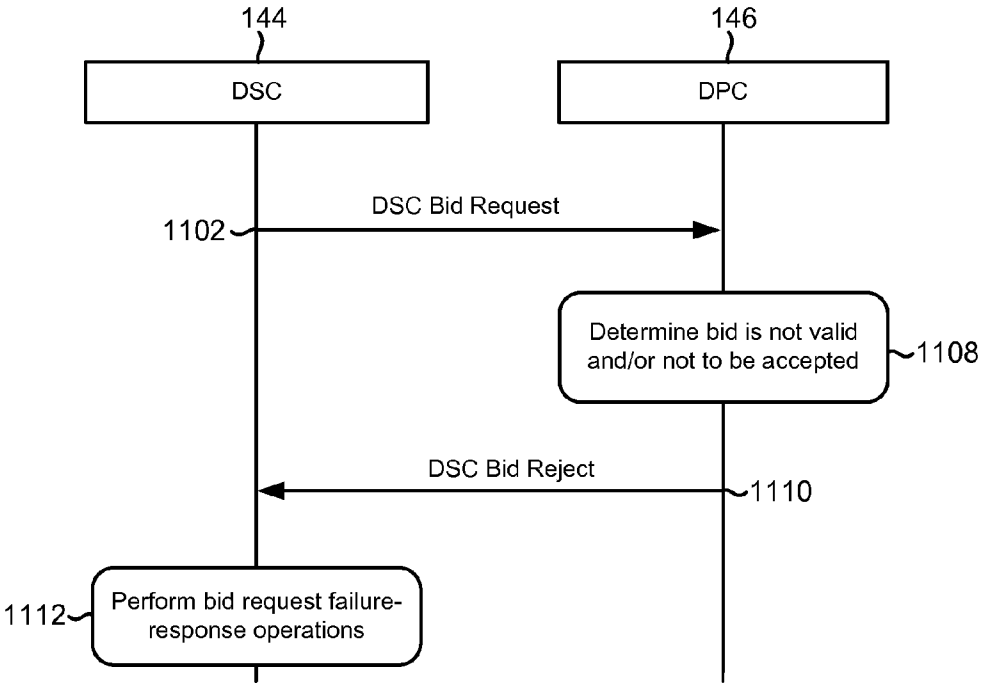


FIG. 11B

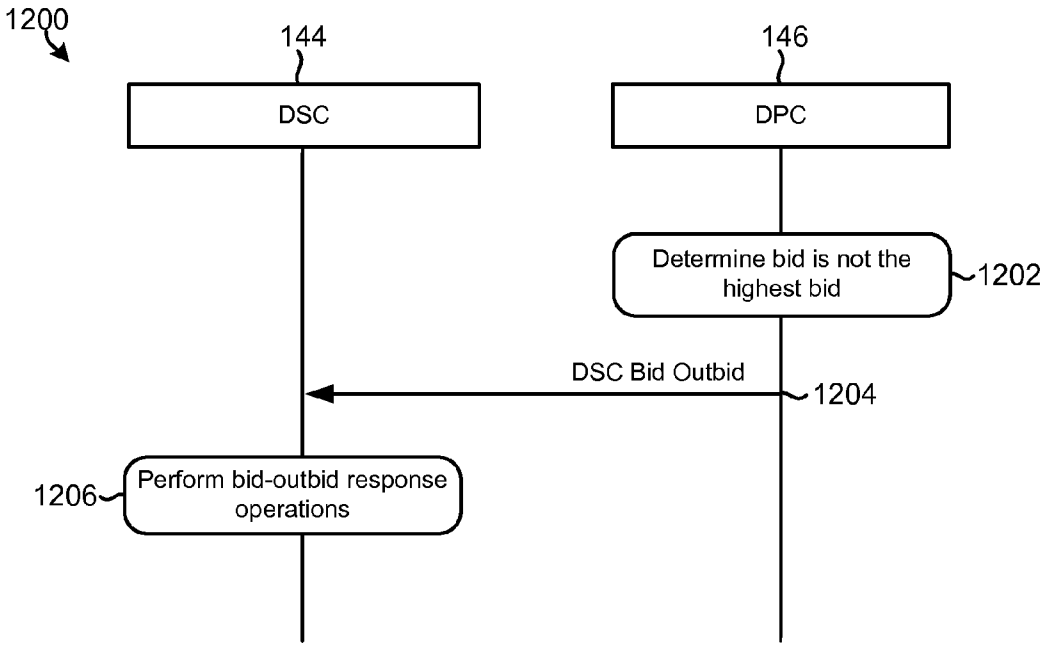


FIG. 12A

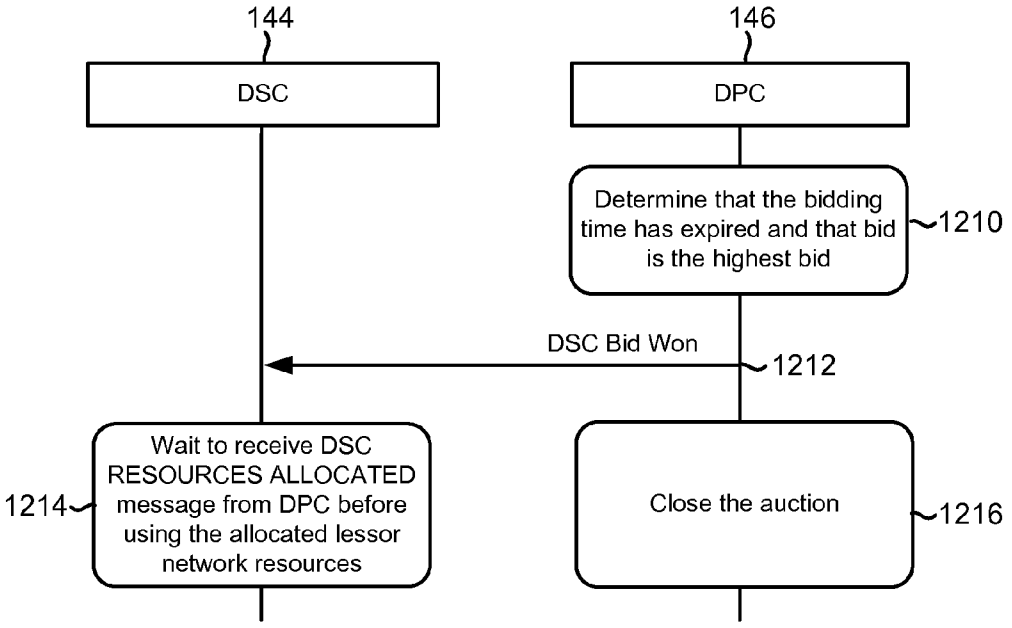


FIG. 12B

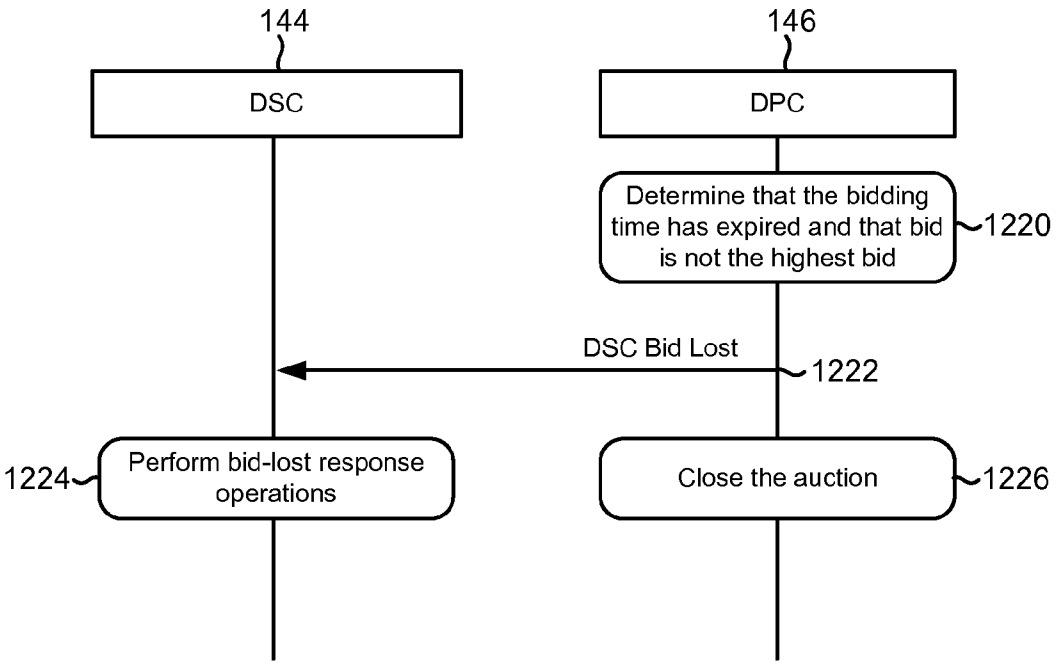


FIG. 12C

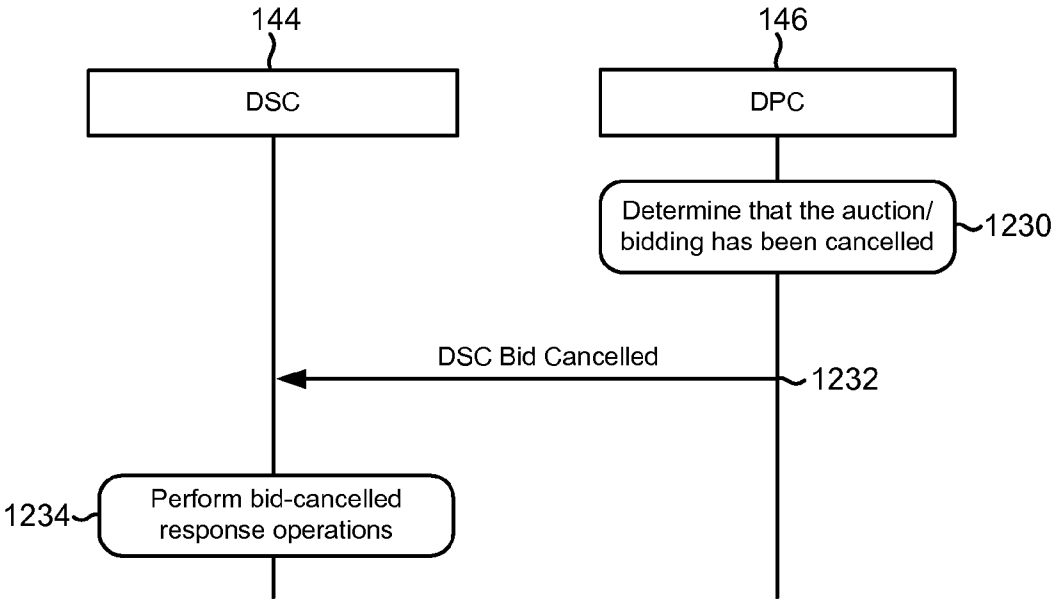


FIG. 12D

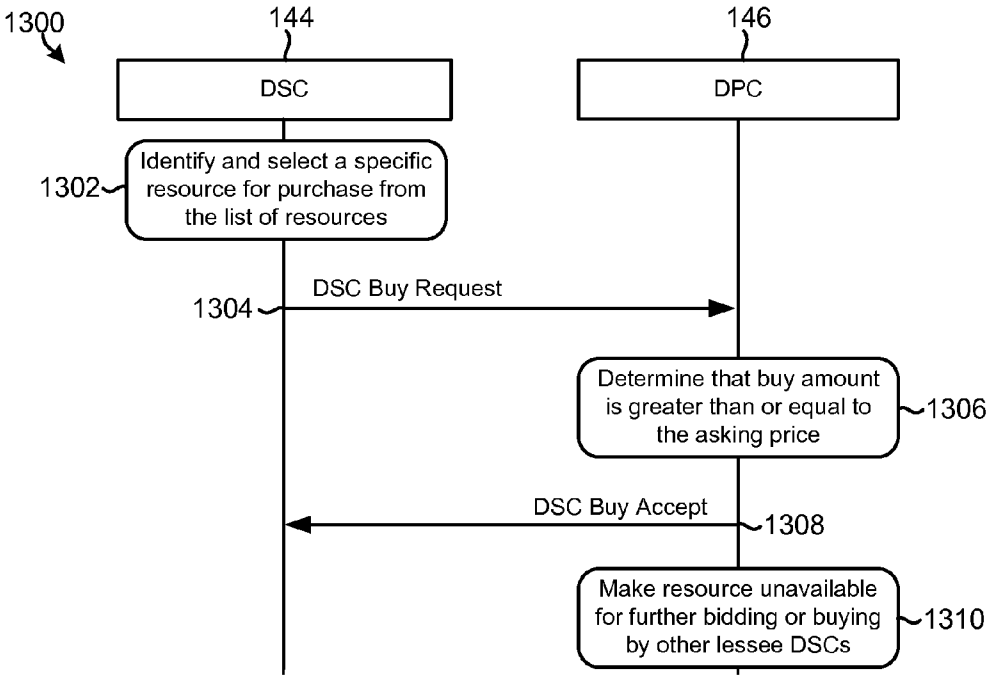


FIG. 13A

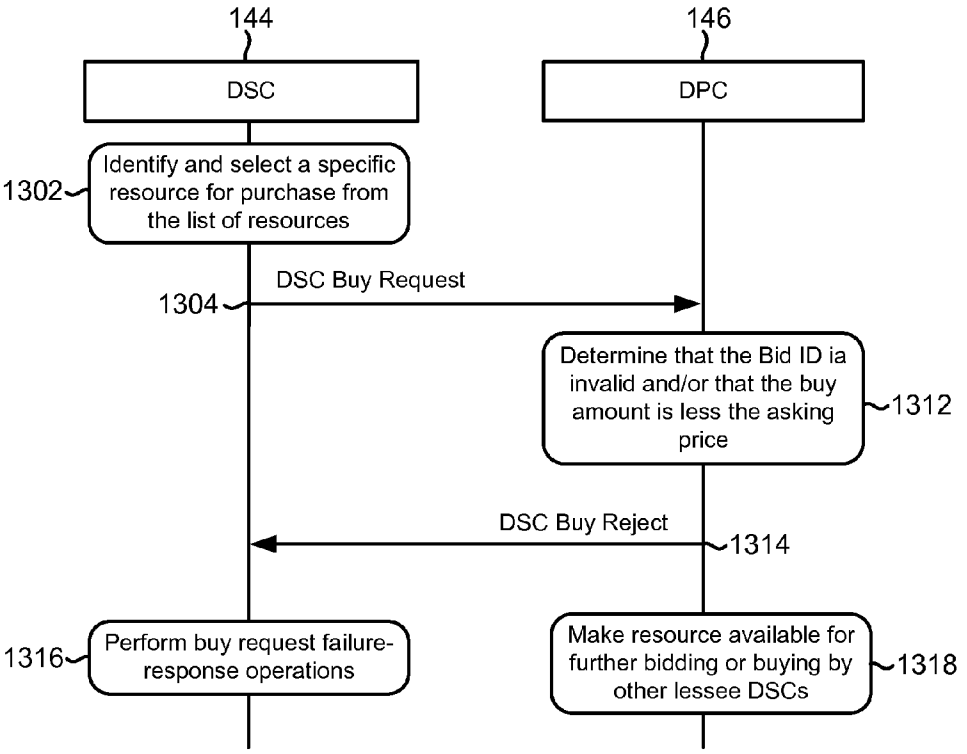


FIG. 13B

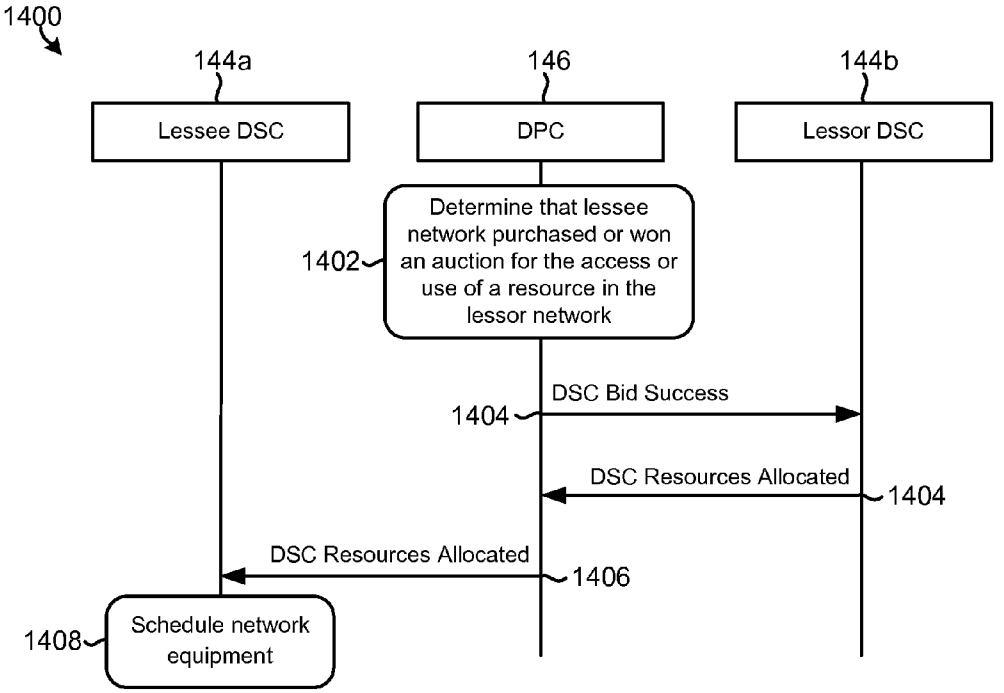


FIG. 14A

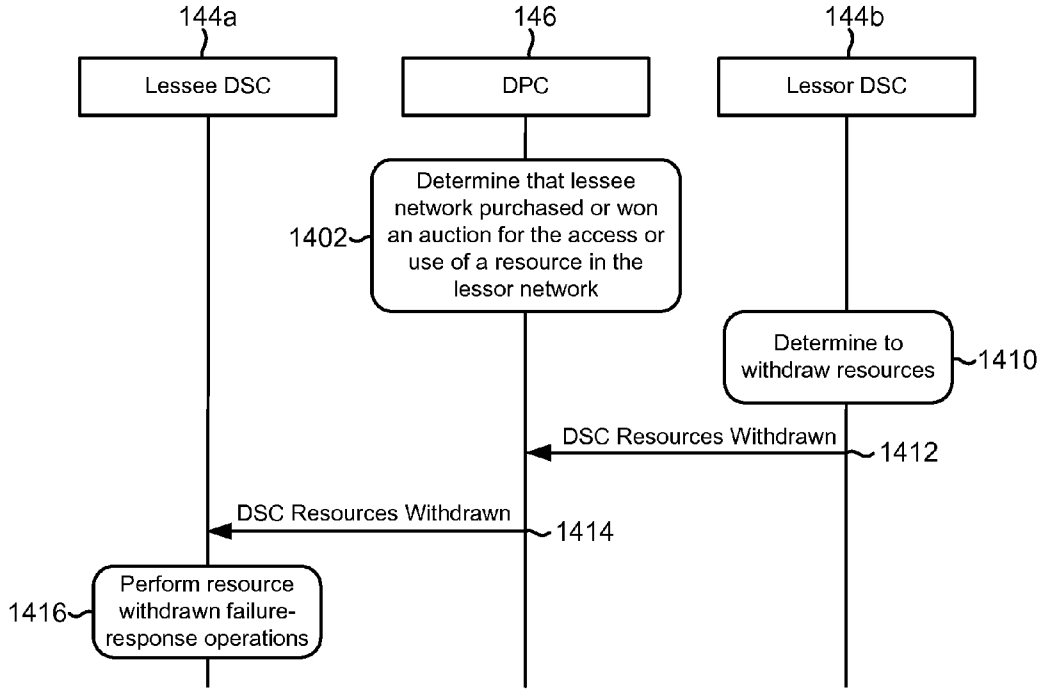


FIG. 14B

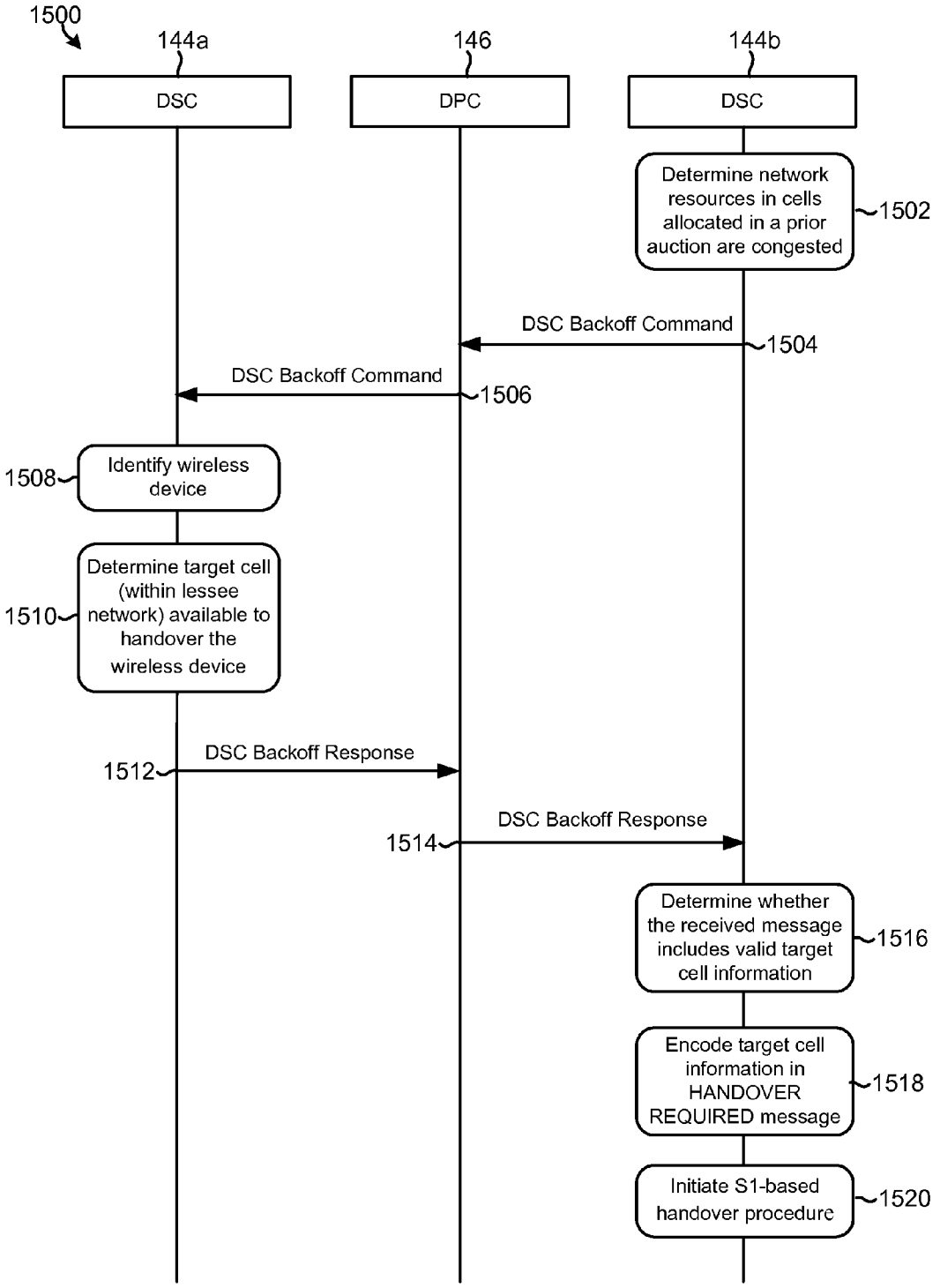

1500
144a
146
144b
DSC
DPC
DSC
Determine network resources in cells allocated in a prior auction are congested
1502
DSC Backoff Command
1504
DSC Backoff Command
1506
1508
Identify wireless device
Determine target cell (within lessee network) available to handover the wireless device
1510
1512
DSC Backoff Response
1514
DSC Backoff Response
Determine whether the received message includes valid target cell information
1516
Encode target cell information in HANDOVER REQUIRED message
1518
Initiate S1-based handover procedure
1520

FIG. 15A

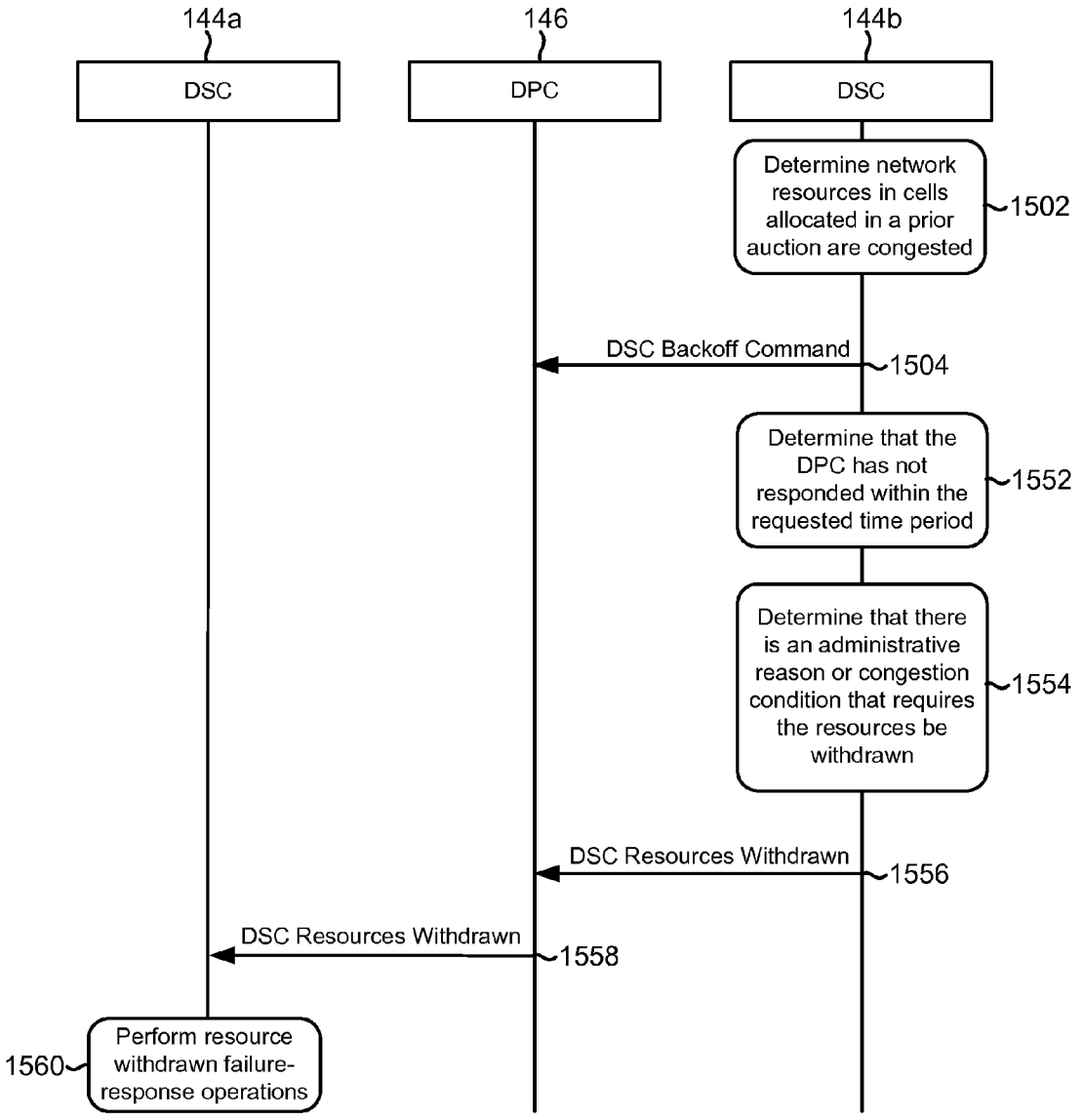

144a
146
144b
DSC
DPC
DSC
Determine network resources in cells allocated in a prior auction are congested
1502
DSC Backoff Command
1504
Determine that the DPC has not responded within the requested time period
1552
Determine that there is an administrative reason or congestion condition that requires the resources be withdrawn
1554
DSC Resources Withdrawn
1556
DSC Resources Withdrawn
1558
Perform resource withdrawn failure-response operations
1560

FIG. 15B

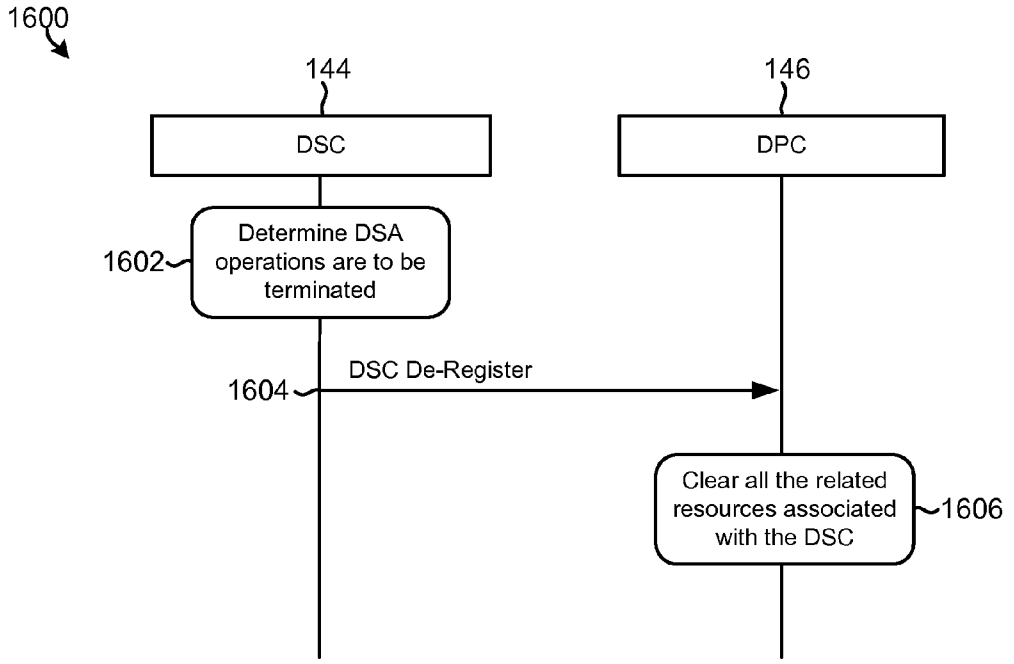


FIG. 16A

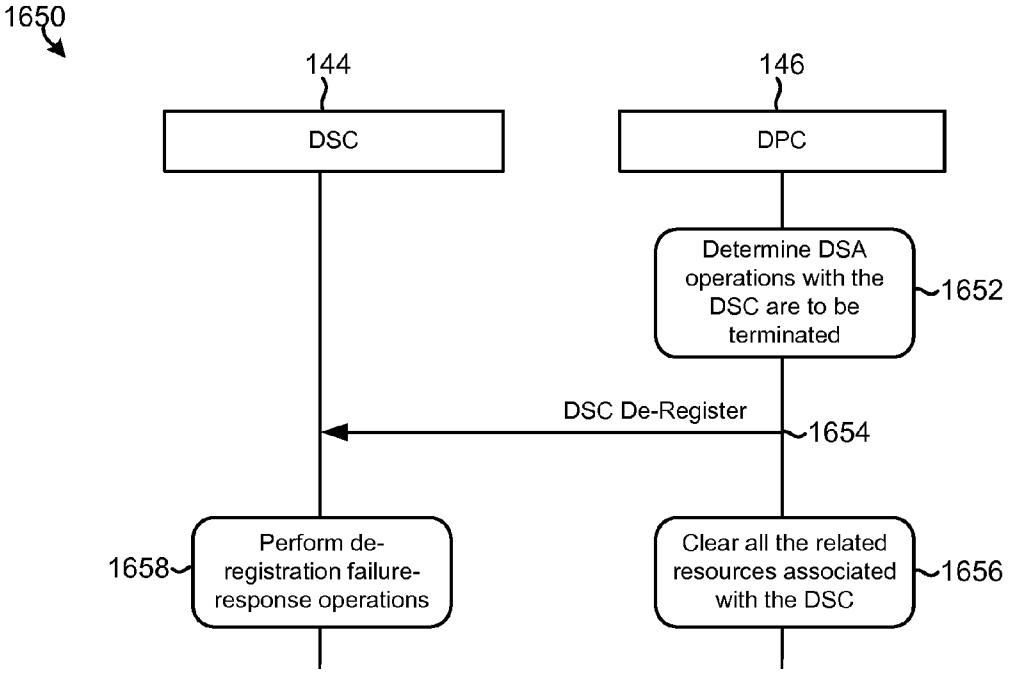


FIG. 16B

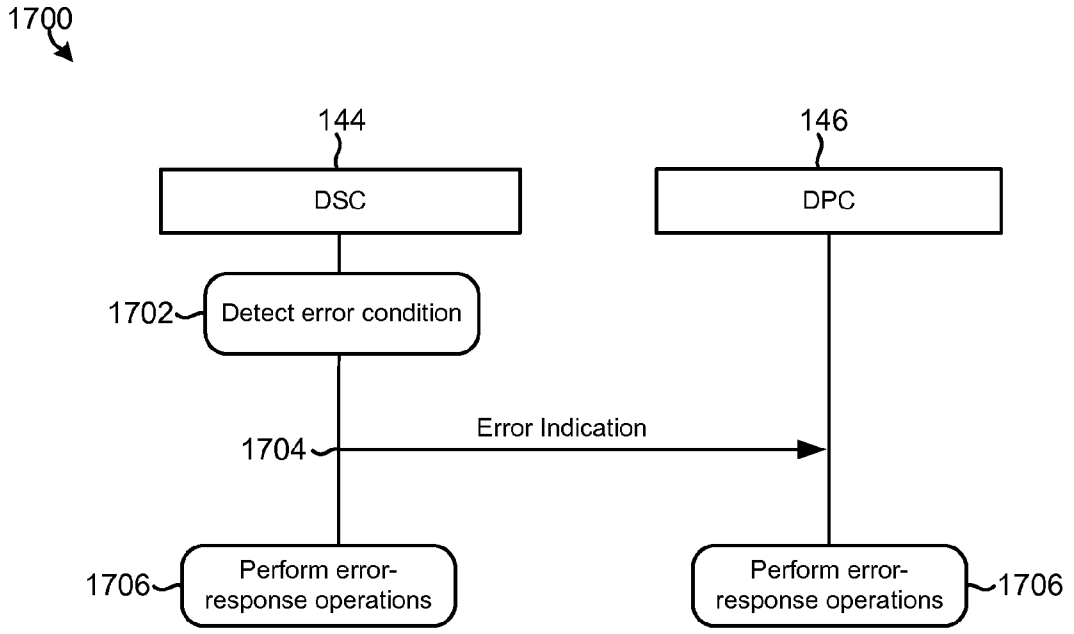


FIG. 17A

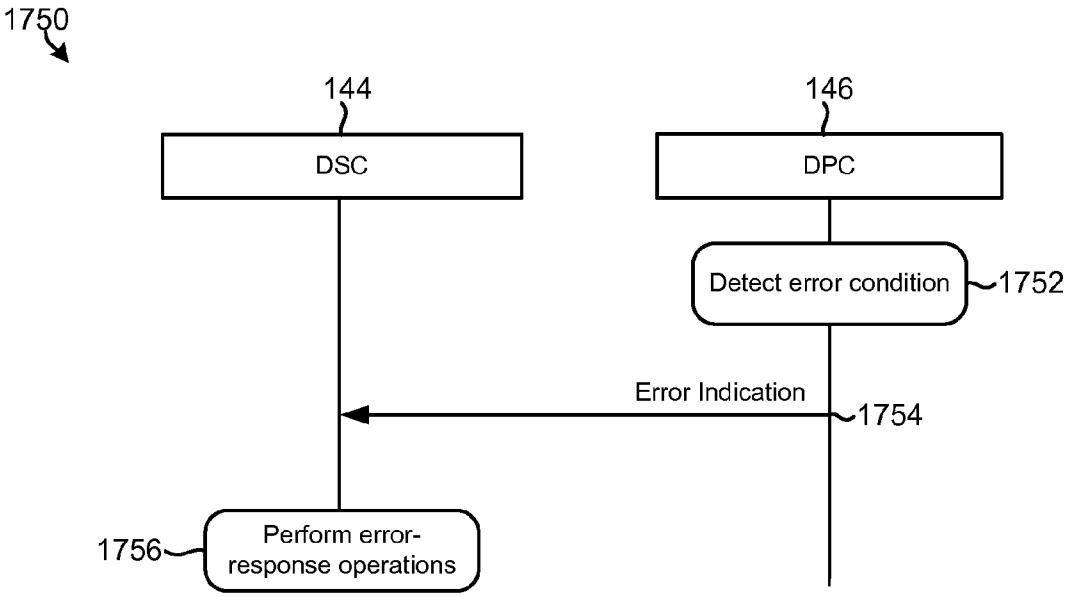


FIG. 17B

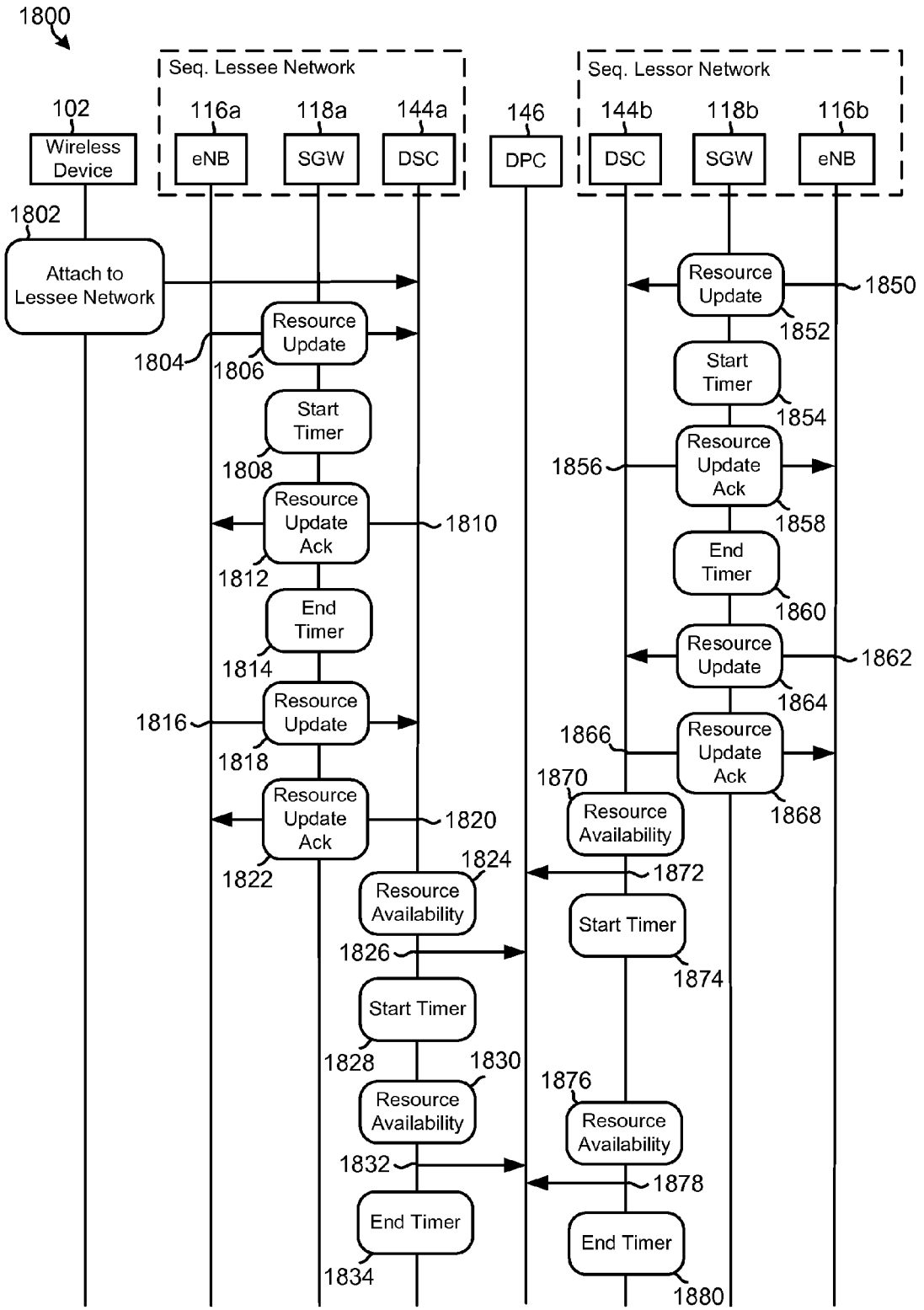

1800
Seq. Lessee Network
Seq. Lessor Network
102
Wireless Device
116a
eNB
118a
SGW
144a
DSC
146
DPC
144b
DSC
118b
SGW
116b
eNB
1802
Attach to Lessee Network
Resource Update
1804
1806
Start Timer
1808
Resource Update Ack
1810
1812
End Timer
1814
Resource Update
1816
1818
Resource Update Ack
1820
1822
Resource Availability
1824
1826
Start Timer
1828
Resource Availability
1830
1832
End Timer
1834
Resource Update
1850
1852
Start Timer
1854
Resource Update Ack
1856
1858
End Timer
1860
Resource Update
1862
1864
Resource Update Ack
1866
1868
Resource Availability
1870
1872
Start Timer
1874
Resource Availability
1876
1878
End Timer
1880

FIG. 18

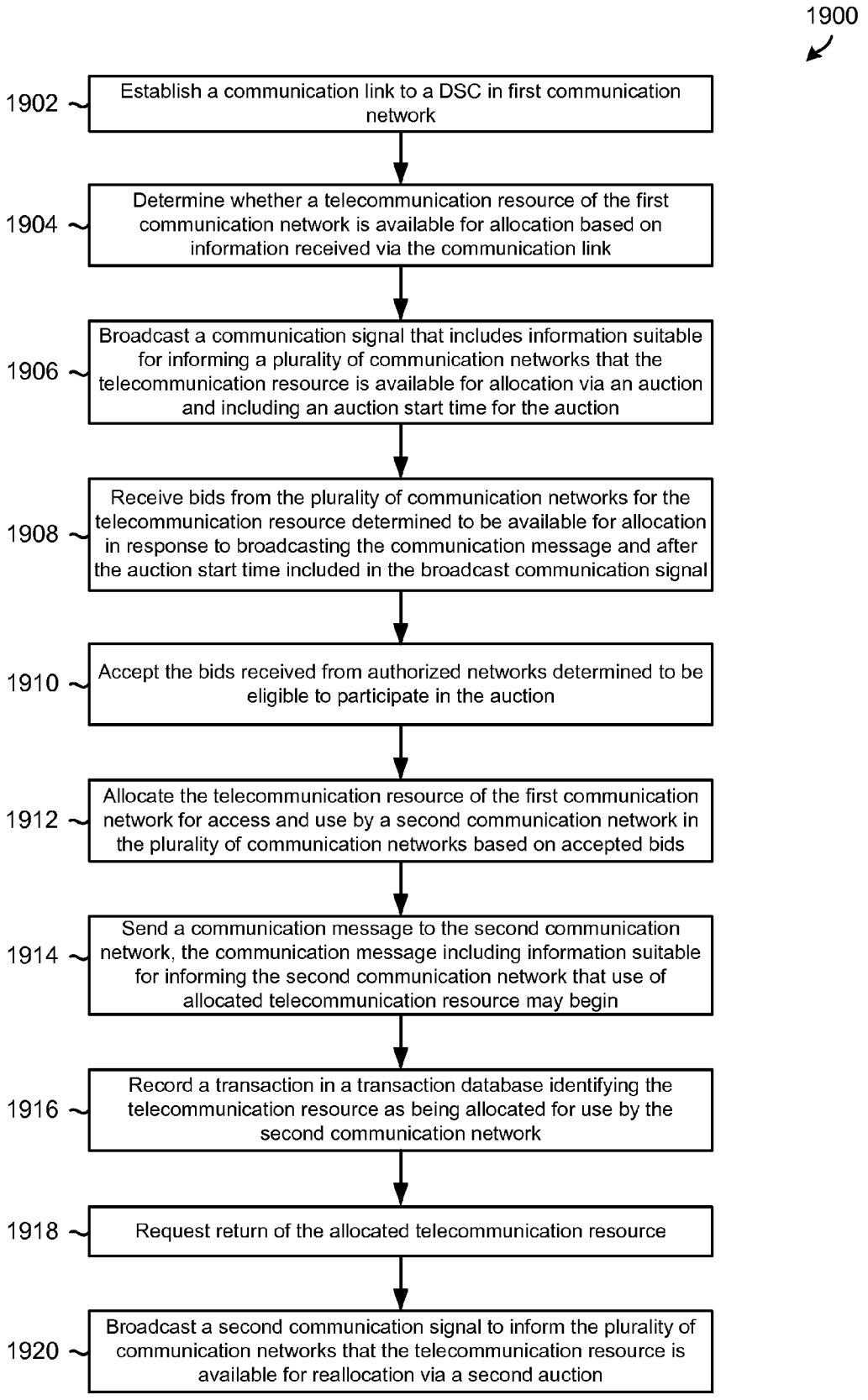

1900
1902
Establish a communication link to a DSC in first communication network
1904
Determine whether a telecommunication resource of the first communication network is available for allocation based on information received via the communication link
1906
Broadcast a communication signal that includes information suitable for informing a plurality of communication networks that the telecommunication resource is available for allocation via an auction and including an auction start time for the auction
1908
Receive bids from the plurality of communication networks for the telecommunication resource determined to be available for allocation in response to broadcasting the communication message and after the auction start time included in the broadcast communication signal
1910
Accept the bids received from authorized networks determined to be eligible to participate in the auction
1912
Allocate the telecommunication resource of the first communication network for access and use by a second communication network in the plurality of communication networks based on accepted bids
1914
Send a communication message to the second communication network, the communication message including information suitable for informing the second communication network that use of allocated telecommunication resource may begin
1916
Record a transaction in a transaction database identifying the telecommunication resource as being allocated for use by the second communication network
1918
Request return of the allocated telecommunication resource
1920
Broadcast a second communication signal to inform the plurality of communication networks that the telecommunication resource is available for reallocation via a second auction

FIG. 19

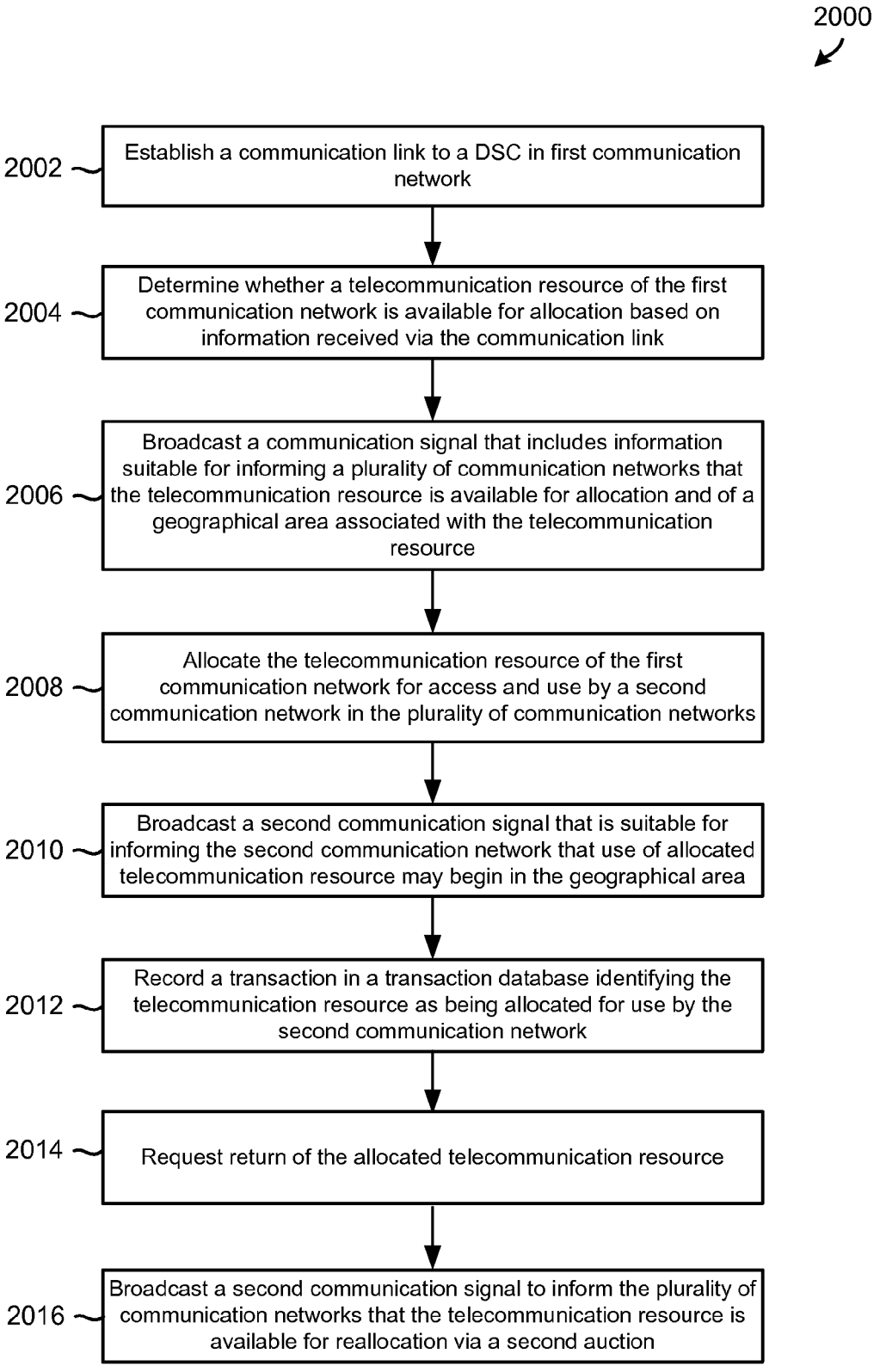

2000
2002
Establish a communication link to a DSC in first communication network
2004
Determine whether a telecommunication resource of the first communication network is available for allocation based on information received via the communication link
2006
Broadcast a communication signal that includes information suitable for informing a plurality of communication networks that the telecommunication resource is available for allocation and of a geographical area associated with the telecommunication resource
2008
Allocate the telecommunication resource of the first communication network for access and use by a second communication network in the plurality of communication networks
2010
Broadcast a second communication signal that is suitable for informing the second communication network that use of allocated telecommunication resource may begin in the geographical area
2012
Record a transaction in a transaction database identifying the telecommunication resource as being allocated for use by the second communication network
2014
Request return of the allocated telecommunication resource
2016
Broadcast a second communication signal to inform the plurality of communication networks that the telecommunication resource is available for reallocation via a second auction

FIG. 20

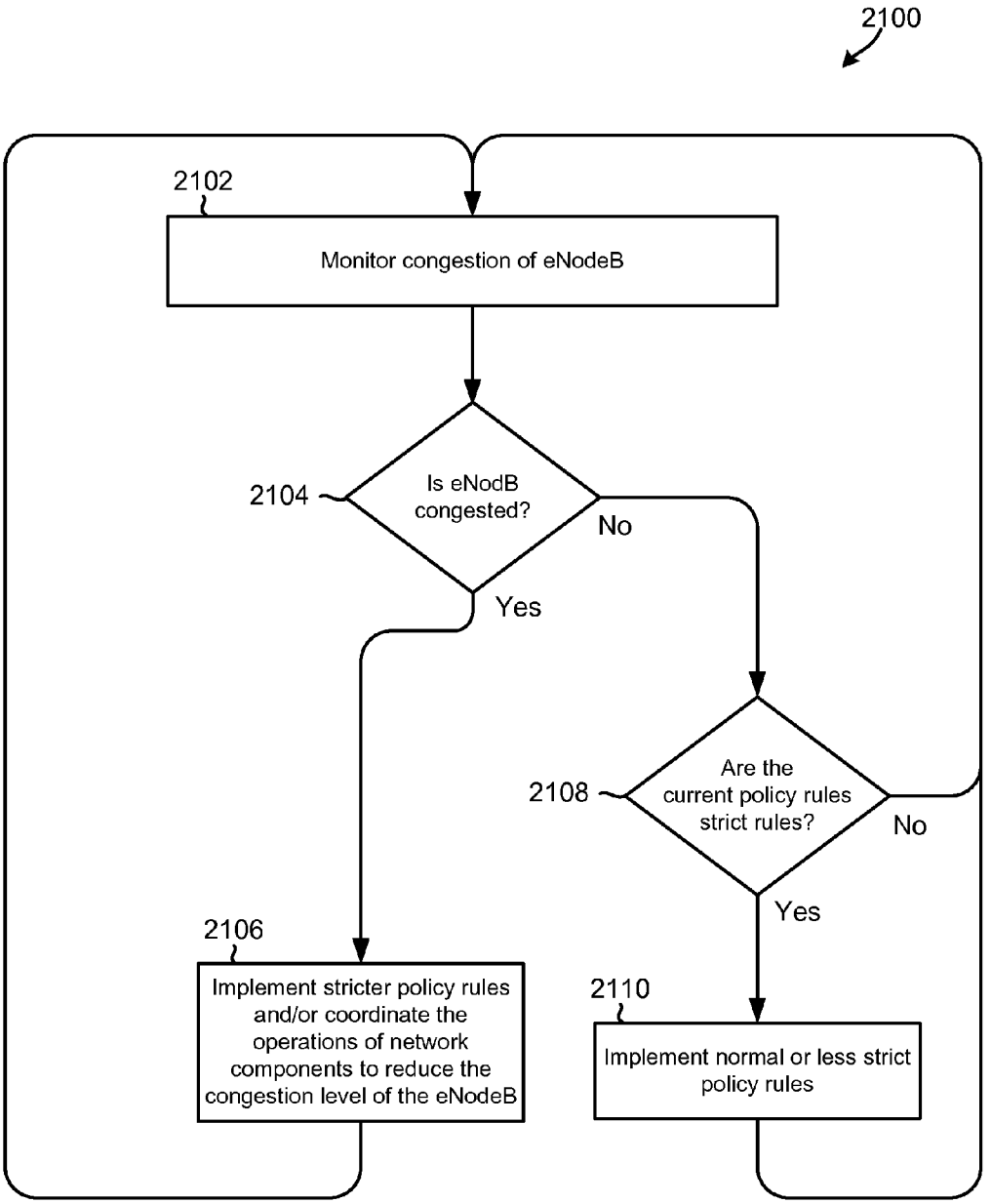

2100
2102
Monitor congestion of eNodeB
2104
Is eNodB congested?
No
Yes
2108
Are the current policy rules strict rules?
No
Yes
2106
Implement stricter policy rules and/or coordinate the operations of network components to reduce the congestion level of the eNodeB
2110
Implement normal or less strict policy rules

FIG. 21

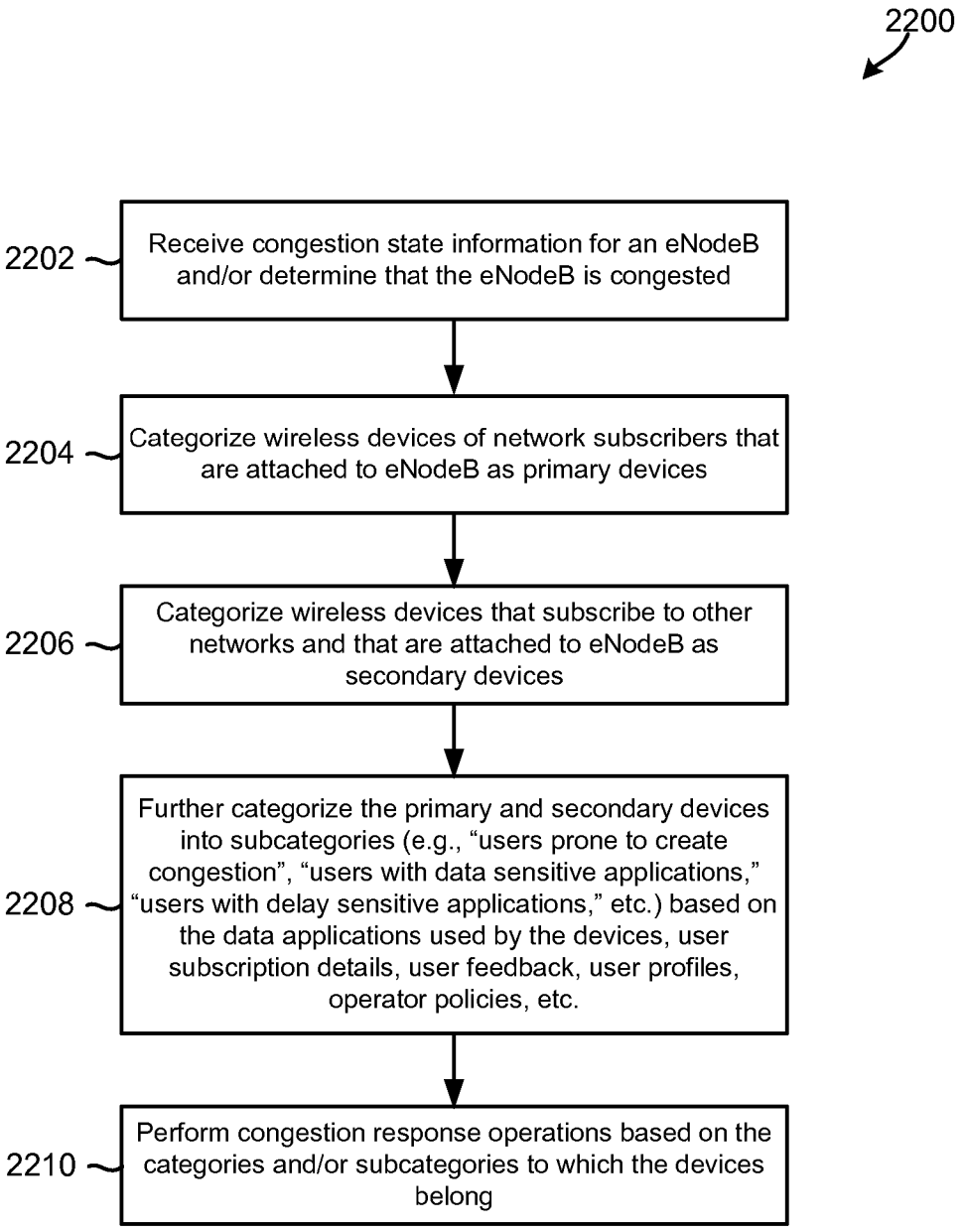

2200
2202
Receive congestion state information for an eNodeB and/or determine that the eNodeB is congested
2204
Categorize wireless devices of network subscribers that are attached to eNodeB as primary devices
2206
Categorize wireless devices that subscribe to other networks and that are attached to eNodeB as secondary devices
2208
Further categorize the primary and secondary devices into subcategories (e.g., “users prone to create congestion”, “users with data sensitive applications,” “users with delay sensitive applications,” etc.) based on the data applications used by the devices, user subscription details, user feedback, user profiles, operator policies, etc.
2210
Perform congestion response operations based on the categories and/or subcategories to which the devices belong

FIG. 22

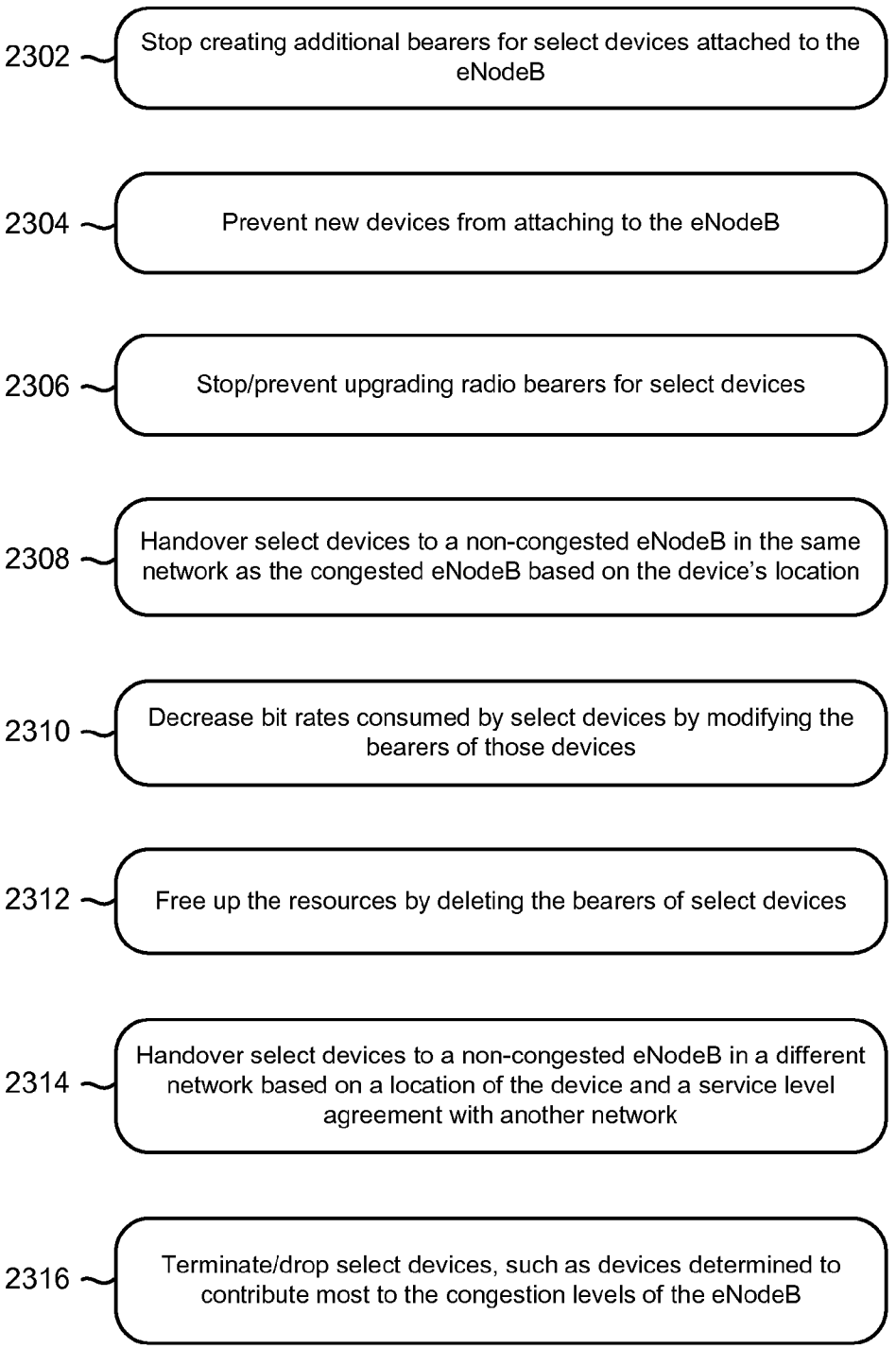

2302
Stop creating additional bearers for select devices attached to the eNodeB
2304
Prevent new devices from attaching to the eNodeB
2306
Stop/prevent upgrading radio bearers for select devices
2308
Handover select devices to a non-congested eNodeB in the same network as the congested eNodeB based on the device's location
2310
Decrease bit rates consumed by select devices by modifying the bearers of those devices
2312
Free up the resources by deleting the bearers of select devices
2314
Handover select devices to a non-congested eNodeB in a different network based on a location of the device and a service level agreement with another network
2316
Terminate/drop select devices, such as devices determined to contribute most to the congestion levels of the eNodeB

FIG. 23

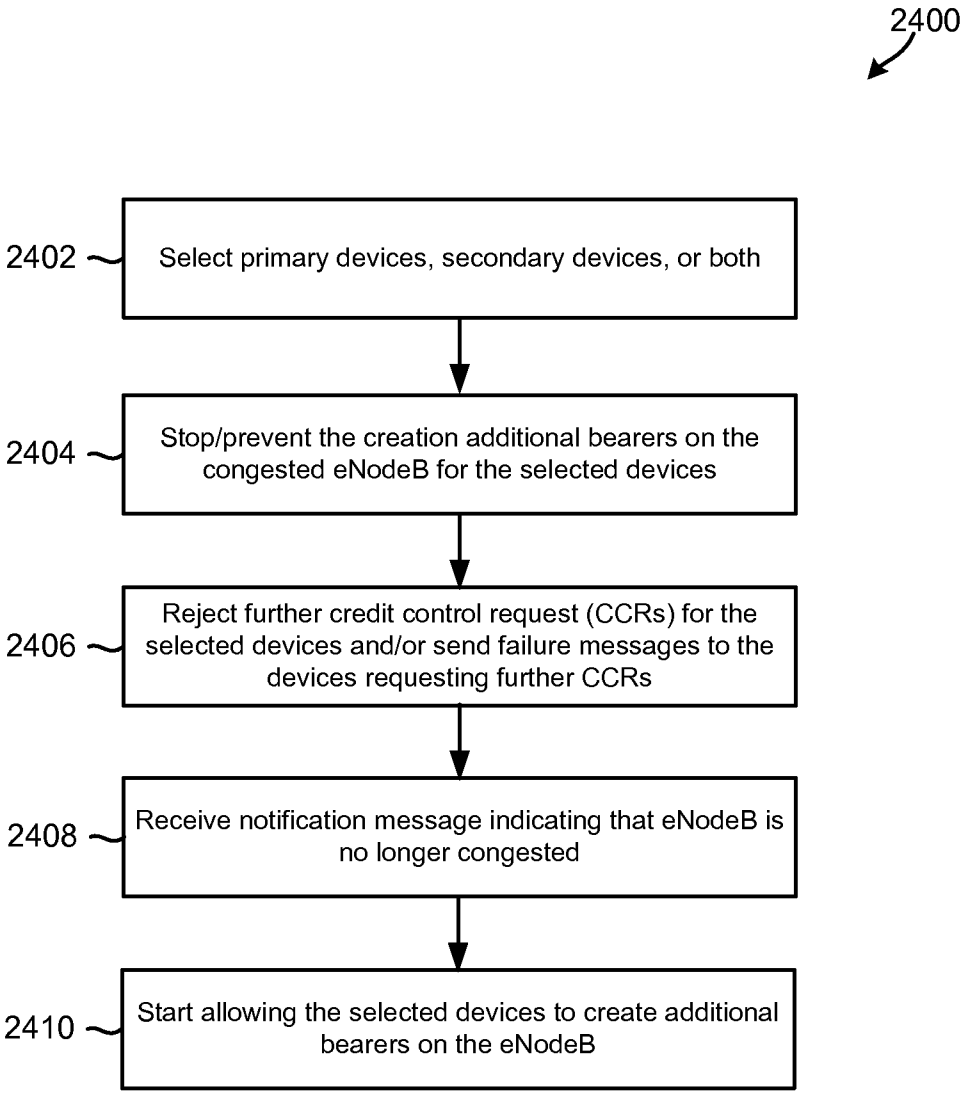

2400
2402
Select primary devices, secondary devices, or both
2404
Stop/prevent the creation additional bearers on the congested eNodeB for the selected devices
2406
Reject further credit control request (CCRs) for the selected devices and/or send failure messages to the devices requesting further CCRs
2408
Receive notification message indicating that eNodeB is no longer congested
2410
Start allowing the selected devices to create additional bearers on the eNodeB

FIG. 24

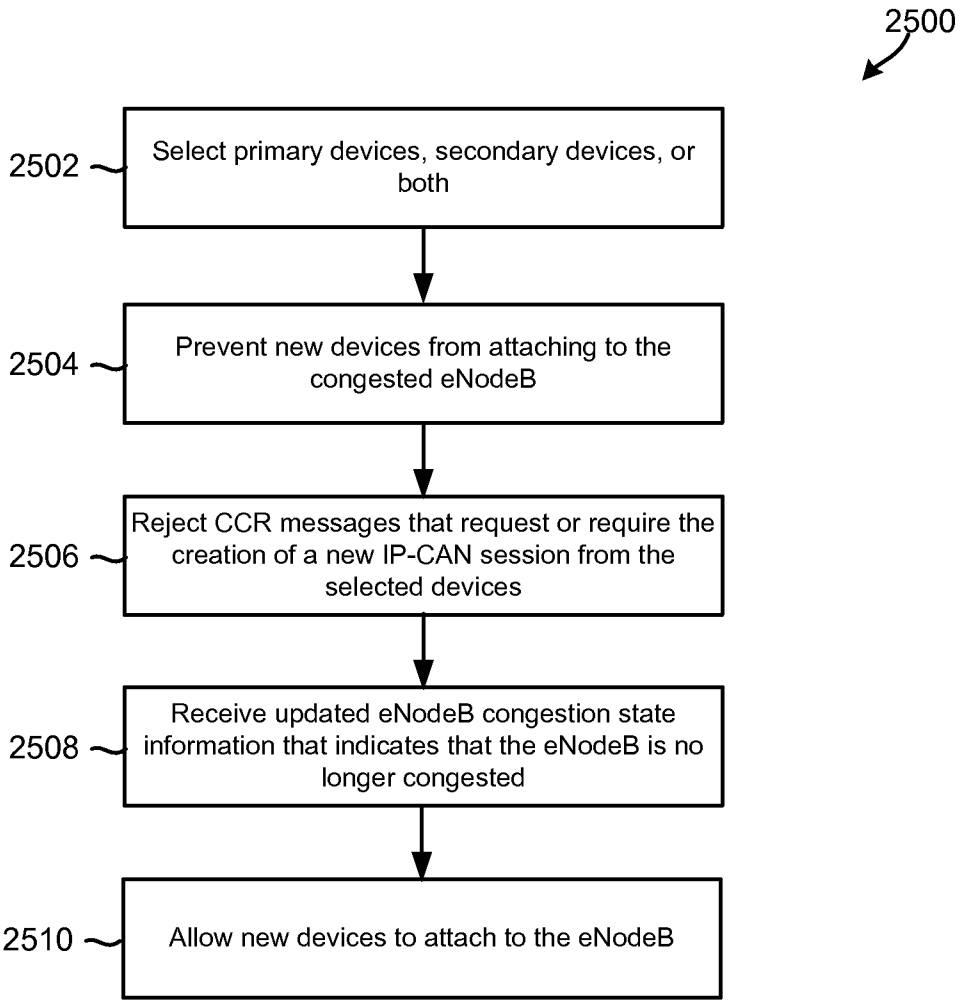

2500
2502
Select primary devices, secondary devices, or both
2504
Prevent new devices from attaching to the congested eNodeB
2506
Reject CCR messages that request or require the creation of a new IP-CAN session from the selected devices
2508
Receive updated eNodeB congestion state information that indicates that the eNodeB is no longer congested
2510
Allow new devices to attach to the eNodeB

FIG. 25

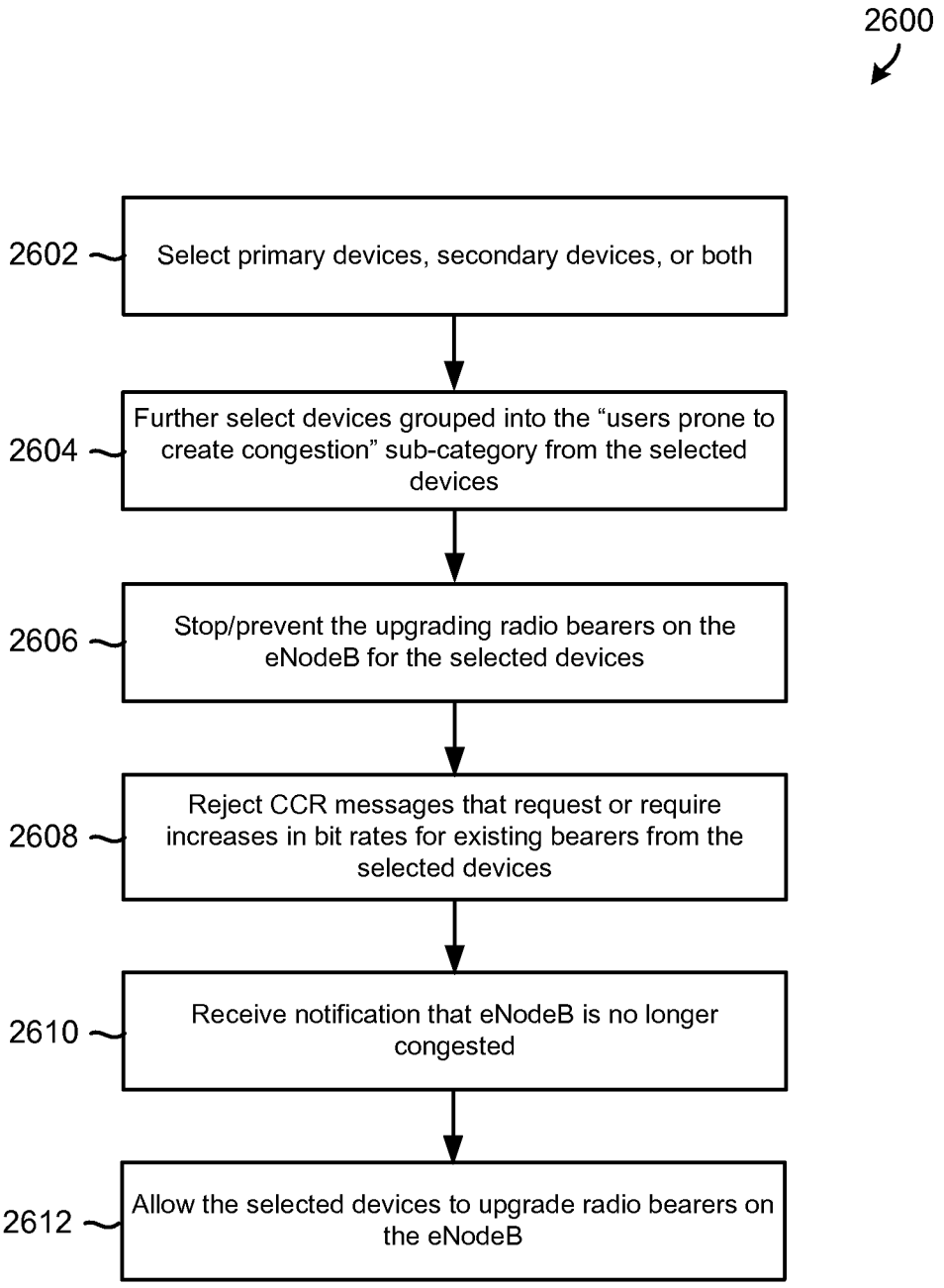

2600
2602
Select primary devices, secondary devices, or both
2604
Further select devices grouped into the "users prone to create congestion" sub-category from the selected devices
2606
Stop/prevent the upgrading radio bearers on the eNodeB for the selected devices
2608
Reject CCR messages that request or require increases in bit rates for existing bearers from the selected devices
2610
Receive notification that eNodeB is no longer congested
2612
Allow the selected devices to upgrade radio bearers on the eNodeB

FIG. 26

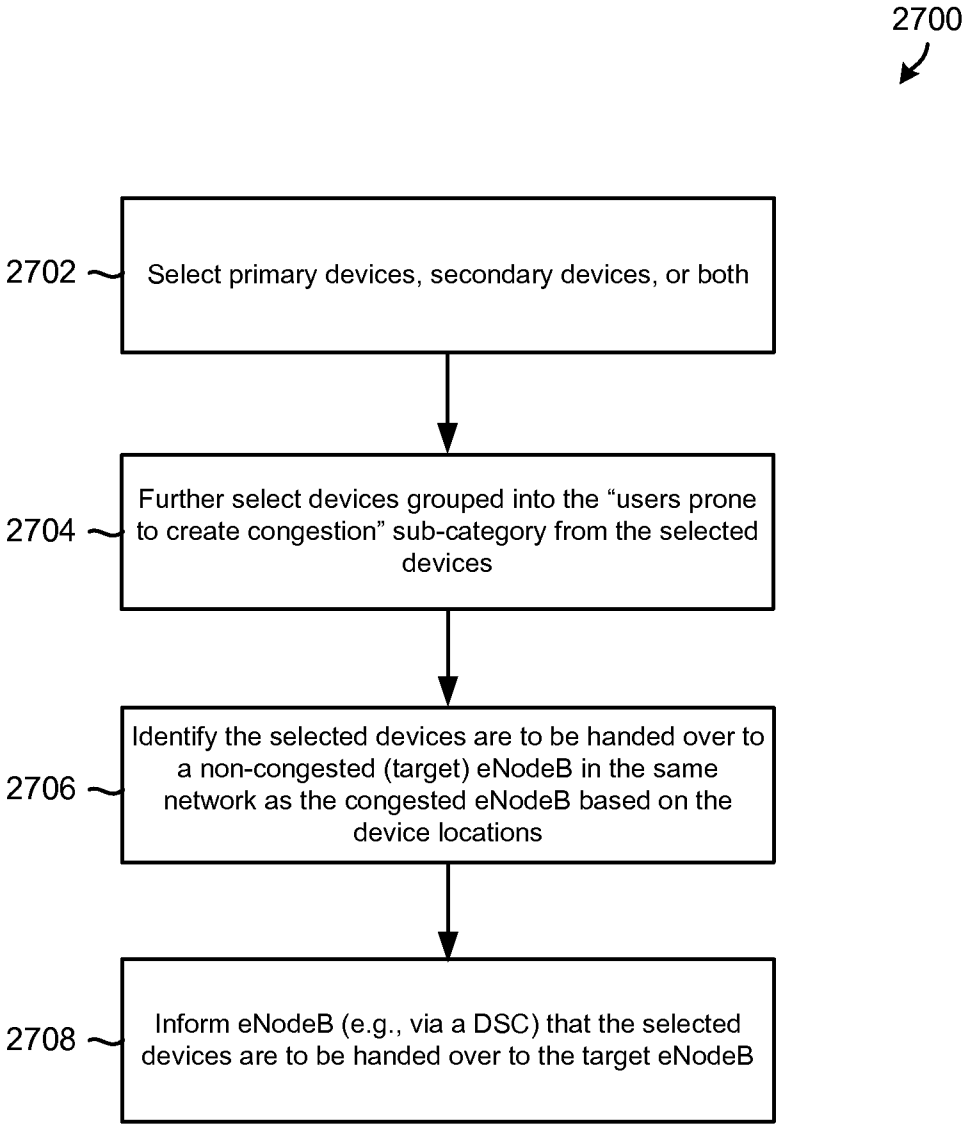

2700
2702
Select primary devices, secondary devices, or both
2704
Further select devices grouped into the "users prone to create congestion" sub-category from the selected devices
2706
Identify the selected devices are to be handed over to a non-congested (target) eNodeB in the same network as the congested eNodeB based on the device locations
2708
Inform eNodeB (e.g., via a DSC) that the selected devices are to be handed over to the target eNodeB

FIG. 27

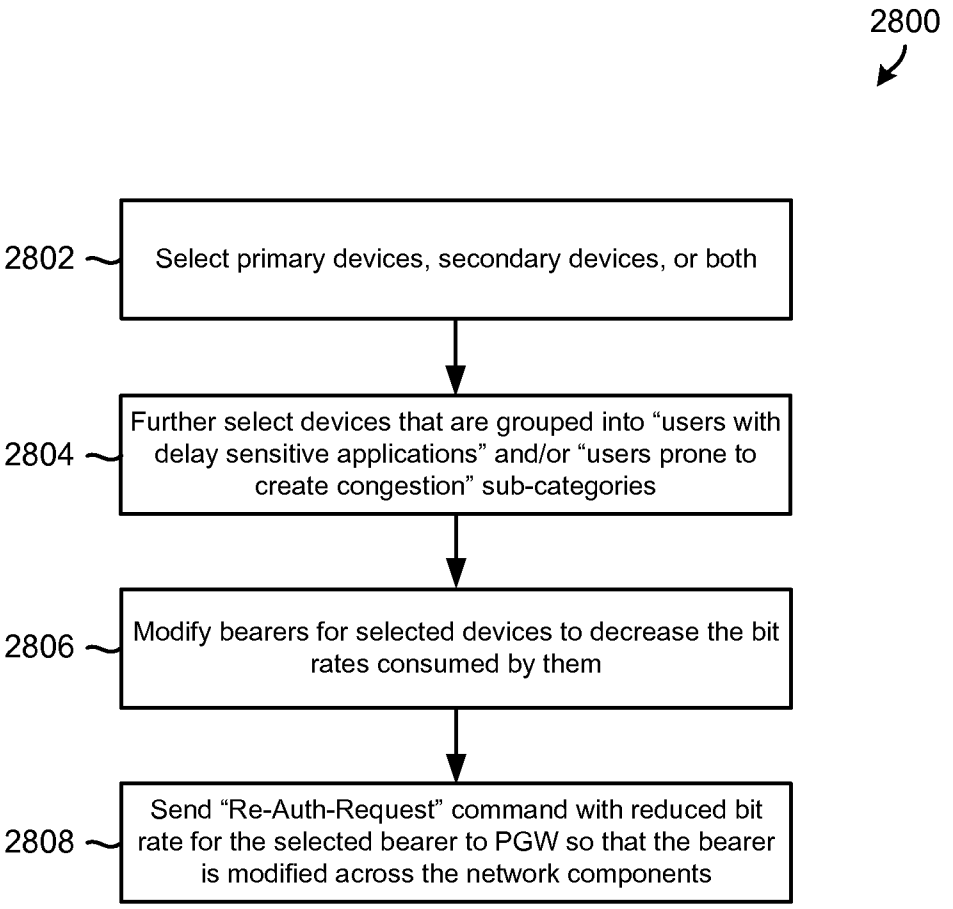

2800
2802
Select primary devices, secondary devices, or both
2804
Further select devices that are grouped into "users with delay sensitive applications" and/or "users prone to create congestion" sub-categories
2806
Modify bearers for selected devices to decrease the bit rates consumed by them
2808
Send "Re-Auth-Request" command with reduced bit rate for the selected bearer to PGW so that the bearer is modified across the network components

FIG. 28

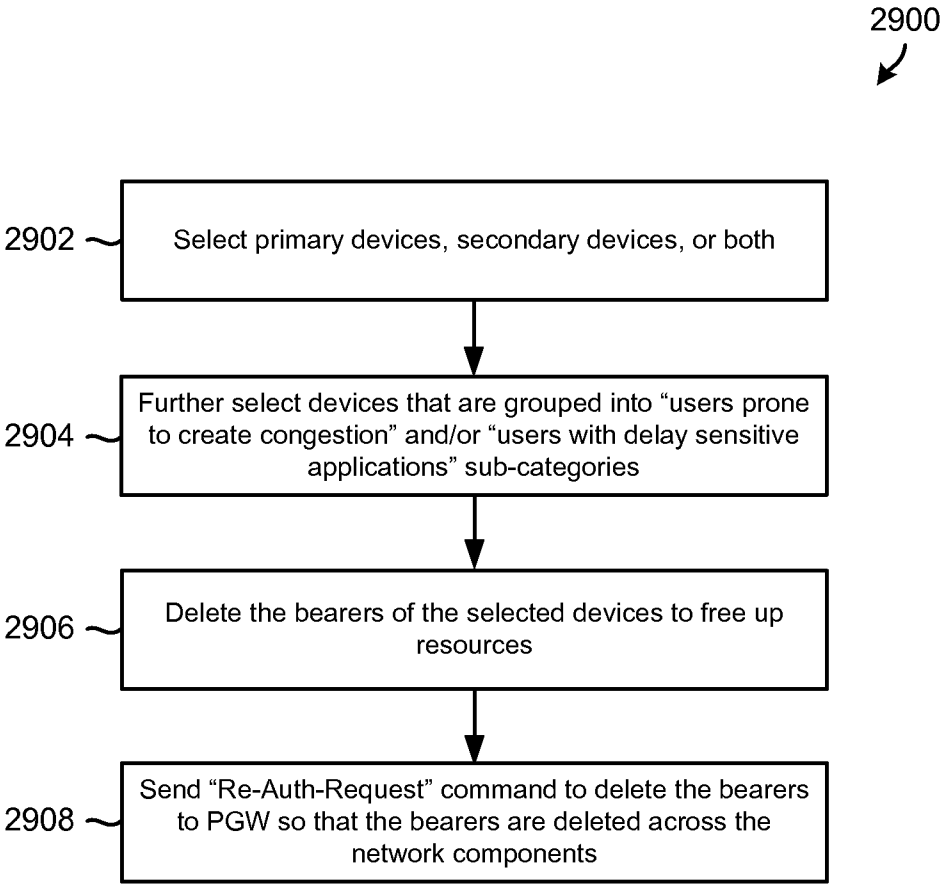

2900
2902
Select primary devices, secondary devices, or both
2904
Further select devices that are grouped into "users prone to create congestion" and/or "users with delay sensitive applications" sub-categories
2906
Delete the bearers of the selected devices to free up resources
2908
Send "Re-Auth-Request" command to delete the bearers to PGW so that the bearers are deleted across the network components

FIG. 29

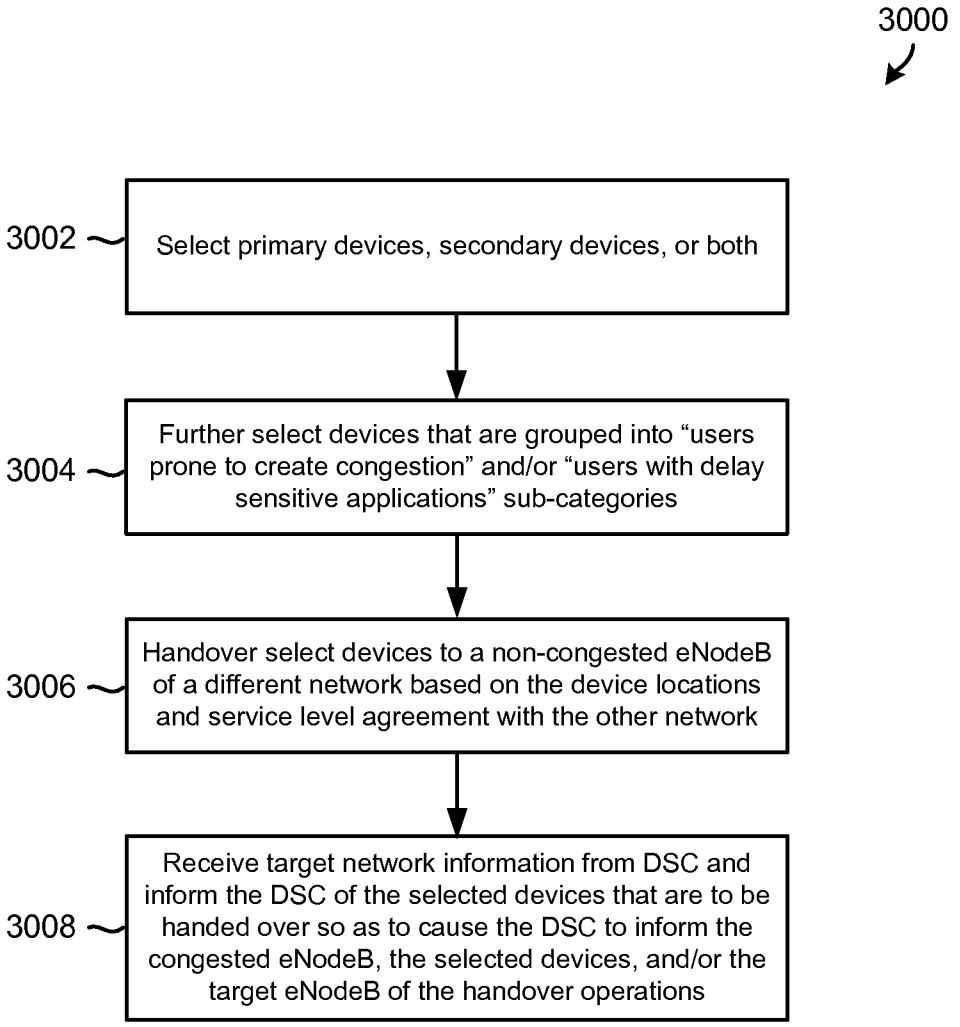

3000
3002
Select primary devices, secondary devices, or both
3004
Further select devices that are grouped into "users prone to create congestion" and/or "users with delay sensitive applications" sub-categories
3006
Handover select devices to a non-congested eNodeB of a different network based on the device locations and service level agreement with the other network
3008
Receive target network information from DSC and inform the DSC of the selected devices that are to be handed over so as to cause the DSC to inform the congested eNodeB, the selected devices, and/or the target eNodeB of the handover operations

FIG. 30

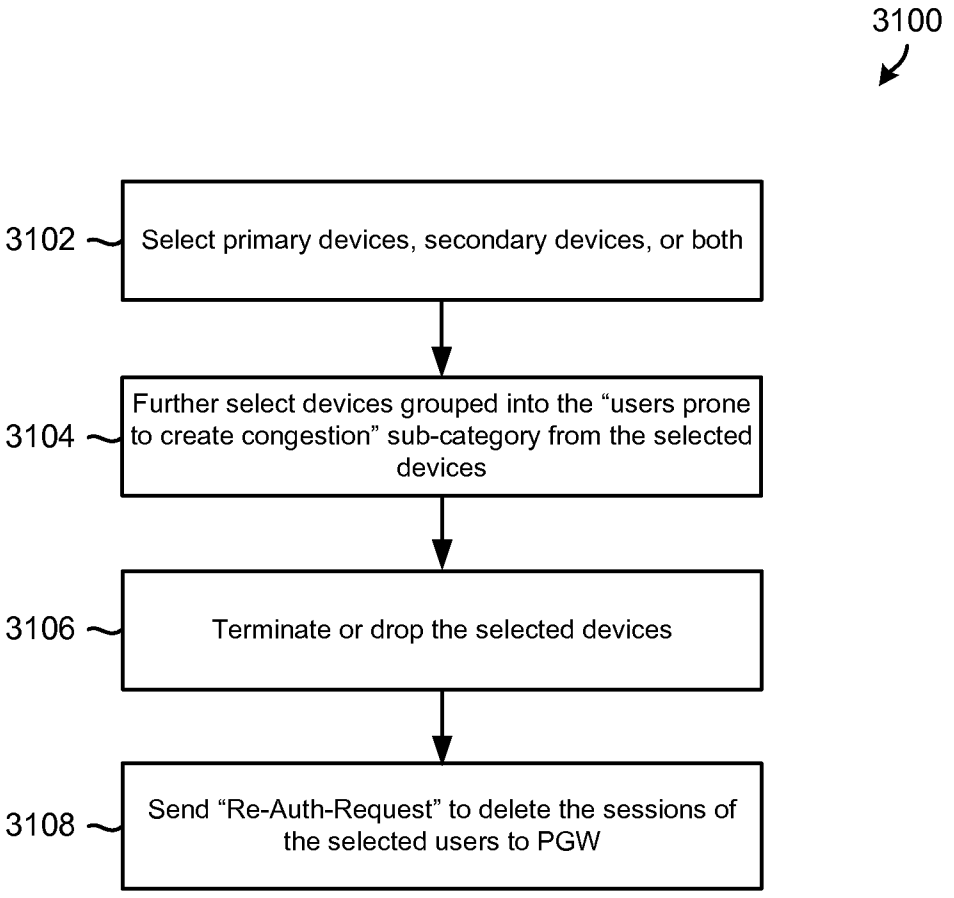

3100
3102
Select primary devices, secondary devices, or both
3104
Further select devices grouped into the "users prone to create congestion" sub-category from the selected devices
3106
Terminate or drop the selected devices
3108
Send "Re-Auth-Request" to delete the sessions of the selected users to PGW

FIG. 31

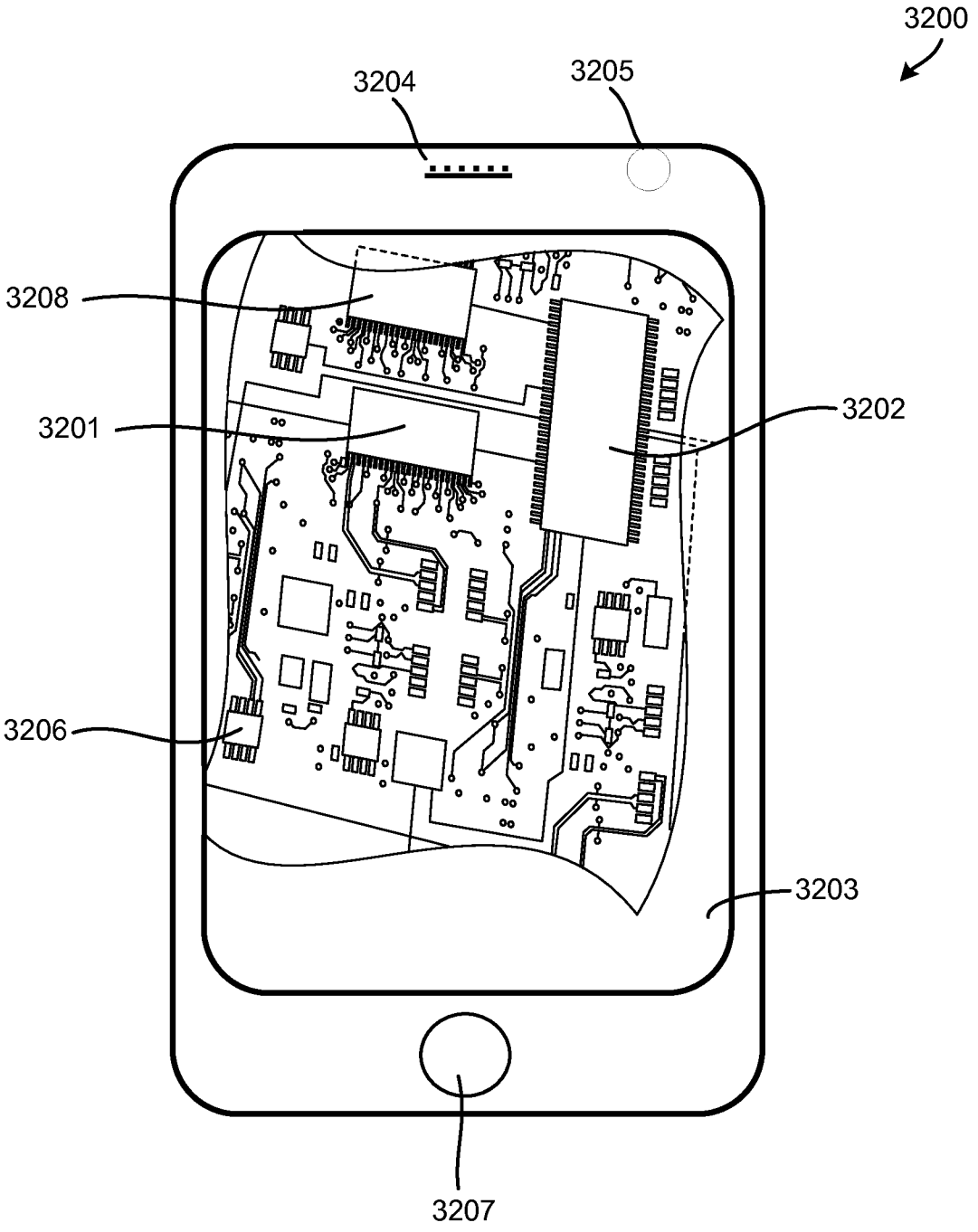


FIG. 32

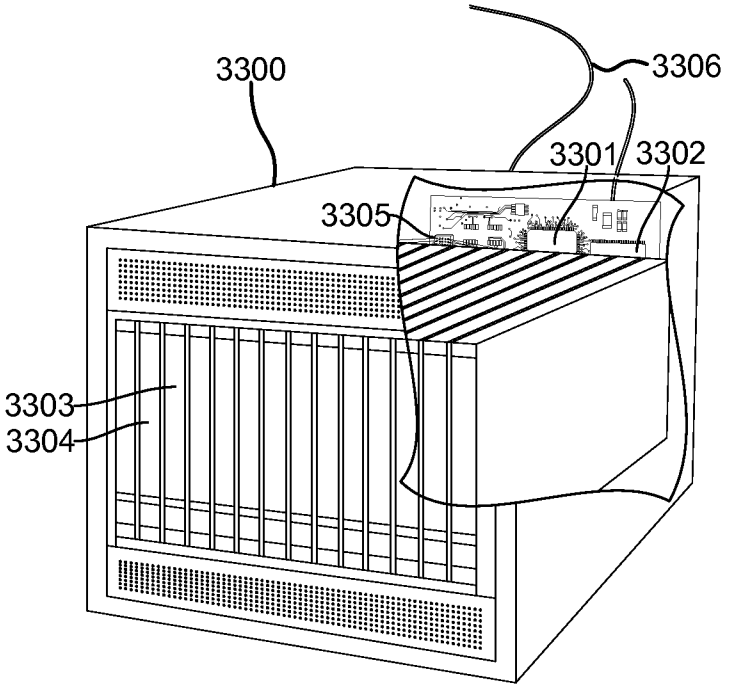


FIG. 33

METHODS AND SYSTEM FOR DYNAMIC SPECTRUM ARBITRAGE POLICY DRIVEN QUALITY OF SERVICE

RELATED APPLICATIONS

[0001] This application claims the benefit of priority to U.S. Provisional Application No. 61/827,937, entitled "Methods and System for Dynamic Spectrum Arbitrage Policy Driven Quality of Service" filed Jun. May 28, 2013, the entire contents of which are hereby incorporated by reference.

BACKGROUND

[0002] With the ever increasing use of wireless communication devices for accessing networks and downloading large files (e.g., video files), there is an increasing demand for radio frequency spectrum. Smart phone users complain about dropped calls, slow access to the Internet and similar problems which are due largely to too many devices trying to access finite radio frequency (RF) bandwidth allocated to such services. Yet parts of the RF spectrum, such as the RF bands dedicated to emergency services (e.g., police, fire and rescue, etc.) go largely unused due to the non-continuous and episodic employment of such voice-radio communication bands. Therefore, improved methods and solutions for dynamically allocating underutilized telecommunication resources (e.g., RF spectrum, etc.) of a first telecommunication network for access and use by wireless devices that subscribe to other networks will be beneficial to the telecommunication networks, service providers, and to the consumers of telecommunication services.

SUMMARY

[0003] The various embodiments include methods of intelligently reducing congestion of an eNodeB via a policy and charging rules function (PCRF) server by receiving eNodeB congestion state information in a processor of a PCRF server, receiving information identifying wireless devices attached to the eNodeB, categorizing each of the identified wireless devices into a category selected from a plurality of categories (a primary device category, a secondary device category, etc.), selecting a subset of the identified wireless devices based on the category into which they are categorized, and performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB. In an embodiment, performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include preventing new devices from attaching to the eNodeB. In a further embodiment, performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include and/or preventing the creation of additional bearers by the selected wireless devices.

[0004] In a further embodiment, the method may include categorizing the identified devices into one or more subcategories (e.g., devices prone to create congestion, etc.), and selecting the subset of the identified wireless devices may include selecting the subset of wireless devices based on the category (e.g., primary, secondary, or both) and the one or more subcategories into which they are categorized. In a further embodiment, categorizing the identified devices into one or more subcategories may include determining whether any of the identified wireless devices are prone to create congestion, determining whether any of the identified wireless devices include data sensitive applications, and determining whether the identified wireless devices include delay sensitive applications. In an embodiment, the categorizing the identified devices into one or more subcategories may include categorizing the wireless devices into one or more of prone to create congestion subcategory, a data sensitive subcategory, and a delay sensitive subcategory.

[0005] In a further embodiment, performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include preventing radio bearer upgrades on the eNodeB for the selected wireless devices. In a further embodiment, performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include determining a location of a selected device, identifying a non-congested target eNodeB based on the determined location, and performing handover operations to hand over the selected device to the non-congested target eNodeB.

[0006] In a further embodiment, performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include modifying bearers for the selected devices so as to decrease the bit rates consumed by the selected devices. In a further embodiment, performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include deleting bearers for the selected devices so as to free up resources consumed by the selected devices.

[0007] In a further embodiment, performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include performing handover operations (or causing/instructing an eNodeB to perform handover operations) to hand over the selected devices to a non-congested target eNodeB in a different network than the PCRF. In a further embodiment, performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include causing the eNodeB to drop the selected devices.

[0008] In a further embodiment, the method may include determining in a dynamic spectrum policy controller (DPC) server an amount of radio frequency (RF) spectrum resources available for allocation within a first communication network that includes the PCRF server and eNodeB by communicating with a first dynamic spectrum controller (DSC) server in the first communication network. In further embodiment, the method may include allocating by the DPC server a portion of available RF spectrum resources of the first communication network for access and use by wireless devices of a second communication network, and informing the second communication network that use of allocated RF spectrum resources may begin, such as by communicating with a second DSC server in the second communication network.

[0009] In a further embodiment, categorizing each of the identified wireless devices may include categorizing the wireless devices of the second communication network into the secondary device category. In a further embodiment, the method may include monitoring network resource usage in an eNodeB processor of the eNodeB, determining in the eNodeB processor whether the usage of network resources exceeds a threshold value, and restricting originations of new sessions of wireless devices attached to the eNodeB and restricting handins of additional wireless devices to the eNodeB in response to determining that the usage of network resources exceeds the threshold value.

[0010] In a further embodiment, the method may include classifying the wireless devices attached to the eNodeB into priority groups by the eNodeB processor, and restricting originations of new sessions of the wireless devices attached to the eNodeB may include restricting originations of new sessions of the wireless devices based on the priority groups. In a further embodiment, the method may include sending by the eNodeB processor the eNodeB congestion state information and information identifying wireless devices attached to the eNodeB in response to determining that the wireless devices attached to the eNodeB belong to the same priority group.

[0011] Further embodiments may include a PCRF server computing device that includes a processor configured with processor-executable instructions to perform operations that include receiving eNodeB congestion state information and information identifying wireless devices attached to an eNodeB, categorizing each of the identified wireless devices into a category selected from a plurality of categories, the plurality of categories including primary device category and a secondary device category, selecting a subset of the identified wireless devices based on the category into which they are categorized, and performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB.

[0012] In an embodiment, the processor may be configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include preventing new devices from attaching to the eNodeB. In a further embodiment, the processor may be configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include preventing the creation additional bearers by the selected wireless devices.

[0013] In a further embodiment, the processor may be configured with processor-executable instructions to perform operations further including categorizing the identified devices into one or more subcategories, in which selecting the subset of the identified wireless devices further may include selecting the subset of wireless devices based on the category and the one or more subcategories into which they are categorized. In a further embodiment, the processor may be configured with processor-executable instructions to perform operations such that categorizing the identified devices into one or more subcategories may include determining whether any of the identified wireless devices are prone to create congestion, determining whether any of the identified wireless devices include data sensitive applications, and determining whether any of the identified wireless devices include delay sensitive applications.

[0014] In a further embodiment, the processor may be configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include preventing radio bearer upgrades on the eNodeB for the selected wireless devices. In a further embodiment, the processor may be configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include determining a location of a selected device, identifying a non-congested target eNodeB based on the determined location, and performing handover operations to hand over the selected device to the non-congested target eNodeB.

[0015] In a further embodiment, the processor may be configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include modifying bearers for the selected devices so as to decrease the bit rates consumed by the selected devices. In a further embodiment, the processor may be configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include deleting bearers for the selected devices so as to free up resources consumed by the selected devices.

[0016] In a further embodiment, the processor may be configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include performing handover operations to hand over the selected devices to a non-congested target eNodeB in a different network than the PCRF. In a further embodiment, performing the processor may be configured with processor-executable instructions to perform operations such that congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB may include causing the eNodeB to drop the selected devices.

[0017] Further embodiments include a system that includes an eNodeB, and a PCRF server computing device having a PCRF processor that is coupled to the eNode via a communication link. The PCRF processor may be configured with processor-executable instructions to perform operations that include receiving eNodeB congestion state information and information identifying wireless devices attached to the eNodeB from the eNodeB, categorizing each of the identified wireless devices into a category selected from a plurality of categories, the plurality of categories including primary device category and a secondary device category, selecting a subset of the identified wireless devices based on the category into which they are categorized, and performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB.

[0018] Further embodiments may include a computing device that includes a processor configured with processor-executable instructions to perform various operations corresponding to the methods discussed above.

[0019] Further embodiments may include a computing device that includes various means for performing functions corresponding to the method operations discussed above.

[0020] Further embodiments may include a non-transitory processor-readable storage medium having stored thereon processor-executable instructions configured to cause a processor to perform various operations corresponding to the method operations discussed above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate exemplary embodiments of the invention, and, together with the general description given above and the detailed description given below, serve to explain features of the invention.

[0022] FIGS. **1**A through **1**E are system block diagrams illustrating various logical and functions components and communication links in communication systems that may be used to implement the various embodiments.

[0023] FIG. **2**A is a process flow diagram illustrating a dynamic spectrum arbitrage (DSA) method of allocating resources from the perspective of a dynamic spectrum policy controller (DPC) in accordance with an embodiment.

[0024] FIG. **2**B is a message flow diagram illustrating message communications between components of a DSA communication system when allocating resources in accordance with an embodiment.

[0025] FIGS. **3** through **7** are process flow diagrams illustrating an embodiment DSA method of allocating and accessing resources in a communication system that includes a DPC, two dynamic spectrum controllers (DSCs), and a wireless device.

[0026] FIGS. **8**A through **8**C are message flow diagrams illustrating an embodiment dynamic spectrum allocation application part (DSAAP) registration method.

[0027] FIGS. **9**A and **9**B are message flow diagrams illustrating an embodiment DSAAP advertizing method.

[0028] FIGS. **10**A and **10**B are message flow diagrams illustrating an embodiment DSAAP method for communicating a list of available resources.

[0029] FIGS. **11**A and **11**B are message flow diagrams illustrating an embodiment DSAAP bidding method.

[0030] FIGS. **12**A through **12**D are message flow diagrams illustrating an embodiment DSAAP notification method for informing participating networks of the results of the bidding operations.

[0031] FIGS. **13**A and **13**B are message flow diagrams illustrating an embodiment DSAAP purchase method for immediately (or near immediately) purchasing a resource.

[0032] FIGS. **14**A and **14**B are message flow diagrams illustrating an embodiment DSAAP allocation method for allocating resources in a lessor network for access and use by components in a lessee network.

[0033] FIGS. **15**A and **15**B are message flow diagrams illustrating an embodiment DSAAP backoff method of selectively handing over a wireless device from a lessor network back to the lessee's network (i.e. its home PLMN).

[0034] FIG. **16**A is a message flow diagram illustrating an embodiment DSC initiated DSAAP de-registration method for terminating DSA operations.

[0035] FIG. **16**B is a message flow diagram illustrating an embodiment DPC initiated DSAAP de-registration method for terminating DSA operations.

[0036] FIG. **17**A is a message flow diagram illustrating a DSC initiated DSAAP error indication method for reporting errors.

[0037] FIG. **17**B is a message flow diagram illustrating a DPC initiated DSAAP error indication method for reporting errors.

[0038] FIG. **18** is an activity diagram illustrating the operations and information flows between various components in a communication system when performing a DSA resource update method.

[0039] FIGS. **19** and **20** are process flow diagrams illustrating embodiment DSA methods of allocating and de-allocating resources between different networks.

[0040] FIG. **21** is a process flow diagram illustrating a method of controlling the congestion levels of an eNodeB in accordance with an embodiment.

[0041] FIG. **22** is a process flow diagram illustrating a method of reducing the congestion level of an eNodeB based on device priorities or categories in accordance with an embodiment.

[0042] FIG. **23** is an illustration of various example congestion response operations that may be performed in response to determining that the eNodeB is congested.

[0043] FIGS. **24-31** are process flow diagrams illustrating embodiment congestion response methods for reducing the congestion level of an eNodeB.

[0044] FIG. **32** is a component block diagram of an example wireless device suitable for use with the various embodiments.

[0045] FIG. **33** is a component block diagram of a server suitable for use with an embodiment.

DETAILED DESCRIPTION

[0046] The various embodiments will be described in detail with reference to the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts. References made to particular examples and implementations are for illustrative purposes, and are not intended to limit the scope of the invention or the claims.

[0047] As used herein, the terms "wireless device," "wireless device" and "user equipment (UE)" may be used interchangeably and refer to any one of various cellular telephones, personal data assistants (PDA's), palm-top computers, laptop computers with wireless modems, wireless electronic mail receivers (e.g., the Blackberry® and Treo® devices), multimedia Internet enabled cellular telephones (e.g., the iPhone®), and similar personal electronic devices. A wireless device may include a programmable processor and memory. In a preferred embodiment, the wireless device is a cellular handheld device (e.g., a wireless device), which can communicate via a cellular telephone communications network.

[0048] As used in this application, the terms "component," "module," "engine," "manager" are intended to include a computer-related entity, such as, but not limited to, hardware, firmware, a combination of hardware and software, software, or software in execution, which are configured to perform particular operations or functions. For example, a component may be, but is not limited to, a process running on a processor, a processor, an object, an executable, a thread of execution, a program, a computer, a server, network hardware, etc. By way of illustration, both an application running on a computing device and the computing device may be referred to as a component. One or more components may reside within a process and/or thread of execution and a component may be localized on one processor or core and/or distributed between two or more processors or cores. In addition, these components may execute from various non-transitory computer readable media having various instructions and/or data structures stored thereon.

[0049] A number of different cellular and mobile communication services and standards are available or contemplated in the future, all of which may implement and benefit from the various embodiments. Such services and standards include, e.g., third generation partnership project (3GPP), long term evolution (LTE) systems, third generation wireless mobile communication technology (3G), fourth generation wireless mobile communication technology (4G), global system for mobile communications (GSM), universal mobile telecom-

munications system (UMTS), 3GSM, general packet radio service (GPRS), code division multiple access (CDMA) systems (e.g., cdmaOne, CDMA2000™), enhanced data rates for GSM evolution (EDGE), advanced mobile phone system (AMPS), digital AMPS (IS-136/TDMA), evolution-data optimized (EV-DO), digital enhanced cordless telecommunications (DECT), Worldwide Interoperability for Microwave Access (WiMAX), wireless local area network (WLAN), public switched telephone network (PSTN), Wi-Fi Protected Access I & II (WPA, WPA2), Bluetooth®, integrated digital enhanced network (iden), land mobile radio (LMR), and evolved universal terrestrial radio access network (E-UTRAN). Each of these technologies involves, for example, the transmission and reception of voice, data, signaling and/or content messages. It should be understood that any references to terminology and/or technical details related to an individual telecommunication standard or technology are for illustrative purposes only, and are not intended to limit the scope of the claims to a particular communication system or technology unless specifically recited in the claim language.

[0050] A high priority in responding to any emergency or disaster situation is establishing effective communications. In large scale emergency or disaster (both manmade and natural) situations, it is paramount to maintain communications between all first responders and emergency personnel in order to respond, manage, and control the emergency situation effectively. In the absence of effective communication among first responders and other emergency personnel, resources may not be effectively mobilized to the areas which need the resources most. Even in minor emergency situations (e.g., traffic accidents and fires), first responders must be able to call on support assets and coordinate with other services (e.g., public utilities, hospitals, etc.).

[0051] With the ubiquity of wireless device ownership and usage, emergency communication via wireless devices using commercial cellular communication networks often are the most efficient and effective means to mobilize emergency response personnel and resources. Enabling wireless devices to provide effective emergency communications obviates the technical challenges and expense of coordinating radio frequencies among various first responder agencies (e.g., police, fire, ambulance, FEMA, public utilities, etc.). Also, qualified first responders to an accident who are off duty or not ordinarily equipped with radios (e.g., doctors, nurses, retired police, or military personnel) will have or can quickly borrow a wireless device.

[0052] Emergency communications over cellular communication networks is not without problems, however. Cellular and other telecommunication networks ("networks") are designed to accommodate access requests from only a fraction of the total number of wireless devices in a particular cell. At times of emergency or crisis, network resources may become overtaxed when predictable human responses to the situation prompt an extraordinary number of wireless device users within a particular cell to access the network at the same time. Wireless device users may be attempting to alert emergency personnel of the emergency situation (such as a 911 emergency call) or to alert friends or family members that the user is safe despite being in the area of an emergency situation. Some users may be transmitting images of the emergency condition (fire, accident, etc.) to news services or friends. In a wide scale situation, emergency responders using wireless devices for emergency communications will add to the call volume. Regardless, the predictable increase in call volume during an emergency situation can overwhelm a commercial cellular communications network, particularly in the cell zone encompassing the emergency, thus rendering the network unreliable for emergency response personnel communication usage.

[0053] To overcome these and other limitations of existing solutions, the various embodiments include components configured to provide tiered priority access (TPA) capabilities to deliver quality of service (QoS) and grade of service (GoS) based wireless device communications for first responders. Detailed descriptions of example TPA systems are provided in U.S. Pat. No. 8,275,349 dated Sep. 25, 2012, the entire contents of which are hereby incorporated by reference in their entirety and for all purposes.

[0054] In overview, a TPA system or solution may include various components configured to perform various TPA operations to coordinate, make available and/or provide wireless communication resources to high priority users (e.g., emergency personnel) during times of high congestion or in emergency situations. For example, TPA components may be configured to monitor a wireless network's call volume, determine whether the wireless network call volume exceeds a first pre-determined threshold, partition the wireless network resources based on priorities when the wireless network call volume exceeds the first pre-determined threshold, and reserve a portion of the partitioned resources for high priority usage (i.e., use by wireless devices of authorized emergency personnel). The TPA components may be further configured to monitor incoming and outgoing calls to determine whether a call is made from or to an high priority device (e.g., to or from a pre-registered wireless device or wireless devices of authorized emergency personnel), allow general access to the wireless network resources so long as no call is made from or to high priority device, and restrict general access to the wireless network resources in response to determining that a call is made to or from a high priority device. As such, TPA solutions allow telecommunication systems use more the available resources, and ensure that high priority users can access and use the system when needed.

[0055] In the various embodiments, these and other TPA operations may be performed in (or in conjunction with) a dynamic spectrum arbitrage (DSA) system configured to dynamically manage the availability, allocation, access, and use of telecommunication resources (e.g., RF spectrum, etc.) between two or more networks (e.g., between a lessor network and a lessee network). A detailed description of an example DSA system is provided in U.S. Pat. No. 8,711,721 dated Apr. 29, 2014, the entire contents of which are hereby incorporated by reference in their entirety and for all purposes.

[0056] Briefly, a DSA system may include a dynamic spectrum policy controller (DPC) configured to manage the DSA operations and interactions between two or more networks (e.g., between a lessor network and a lessee network). The DPC may communicate with various network components in a network provider network through one or more dynamic spectrum controller (DSC) components, which may be included in or added to the networks participating in the DSA communications. The DSC component may include wired or wireless connections to eNodeBs, a policy and charging rules function (PCRF) component/server, and various other network components. The DSC may communicate with the DPC component to offer, allocate, request, and/or receive resources to and from other networks. This allows two or

more networks to collaborate and make better use their resources (e.g., by leasing resources during times of high congestion, leasing out resources when they are not in use, etc.).

[0057] In the various embodiments, the DPC, DSC, PCRF, eNodeB, and other network components may be configured to communicate and perform various operations that together provide DSA-TPA solutions that more efficiently manage the availability and use of the telecommunication resources, and better prioritize access to the available resources. These components may also be configured to perform DSA-TPA operations so as to better account for detected network activity, user traffic, nature of data utilization of the users/subscribers, user profiles, and congestion levels of two or more participating networks.

[0058] In an embodiment, an eNodeB may be configured to classify or organize the wireless devices into priority groups or classes, such as primary users (e.g., first responders, network subscribers, etc.) and secondary users (e.g., non-priority users, roaming devices, visiting devices that subscribe to other networks, etc.). The eNodeB may be configured to shape the network activity of wireless devices based on the priority groups/classes. In an embodiment, the eNodeB may shape the network activity such that wireless devices belonging to a higher priority group are allocated a larger percentage of the available network resources (e.g., bandwidth, etc.) as the network activity increases.

[0059] As an example, the DSA-TPA may include an eNodeB configured to monitor network activity (e.g., call or data volume, resource usage, congestion, number of active connections, etc.) to determine whether the network activity exceeds two or more thresholds. When the network activity exceeds a first threshold, the eNodeB may reserve radio resources for the primary user's wireless device. When the network activity exceeds a second (or subsequent) threshold, the eNodeB may dynamically "shape" the network activity of the secondary user's wireless device. Shaping the network activity of a wireless device may include performing operations to control one or more characteristics of the wireless communication link and/or the data being communicated, such as reducing bandwidth, reducing QoS, restricting the number of services, shedding a connection, transferring a connected device to another eNodeB, performing handoffs, etc.

[0060] Alternatively or in addition, the eNodeB may be configured to monitor network activity and congestion levels at the radio access network (RAN) level, generate congestion state information based on the monitoring, and send the generated congestion state information to a DSC and/or other network components. The eNodeB may be configured to send the congestion state information to the DSC and/or other network components periodically, in response to detecting congestion, and/or in response to detecting a significant change in congestion levels.

[0061] The congestion state information may identify a current congestion state (e.g., Normal, Minor, Major, Critical, etc.) of the eNodeB and/or other network components. Each congestion state may be associated with a congestion level. For example, a "Normal" congestion state may indicate that a network component (e.g., eNodeB, etc.) is operating under normal load (e.g., user traffic is within the normal operating range, etc.). A "Minor" congestion state may indicate that the network component is experiencing congestion and/or operating under an above-average load. A "Major" congestion state may indicate that the network component is experiencing significant congestion and/or operating under heavy load. A "Critical" congestion state may indicate that the network component is experiencing severe congestion, experiencing an emergency situation, or operating under an extremely heavy load.

[0062] A first DSC in a first network may be configured to receive congestion state information from eNodeBs in the first network, and send the congestion state information to a DPC component that is outside of the first network. The DSC may also send the congestion state information to various components in the first network, such as a PCRF component. In an embodiment, a PCRF component may be configured to receive congestion state information directly from the eNodeB (e.g., via a direct or indirect communication link).

[0063] In response to receiving the eNodeB congestion state information, the PCRF component may classify, organize, or categorize any or all of wireless devices attached to that eNodeB (and/or another eNodeBs in the same network) into one or more categories and subcategories. The categories into which the PCRF groups the devices may be the same as, different, dependent on, or independent of the priority groups or classes into which the eNodeB classifies or organizes the wireless devices. As an example, the PCRF may categorize wireless devices of network subscribers (i.e., wireless devices that subscribe to the network in which the eNodeB and PCRF are included) that are attached to eNodeB as primary devices/users. The PCRF may categorize wireless devices that subscribe to other networks and that are attached to eNodeB as secondary devices/users.

[0064] In an embodiment, the PCRF may be configured to further categorize the primary and secondary devices/users into one or more subcategories, such as "users prone to create congestion", "users with data sensitive applications," "users with delay sensitive applications," etc. In various embodiments, the PCRF may categorize the devices/users into these and other subcategories based on network, resource, usage, device, and/or user information, such as the data applications used by the devices, user subscription details, user feedback, user profiles, operator policies, etc.

[0065] In various embodiments, the PCRF may be configured to perform various congestion response operations in response to receiving the eNodeB congestion state information, in response to categorizing the devices, in response to determining that the eNodeB is congested or under heavy load, and/or based on the current congestion state of the eNodeB. The PCRF may be configured perform congestion response operations based on the categories and/or subcategories to which the devices belong. As part of these operations, the PCRF may communicate with various network components and/or performing various policy or control operations to accomplish various functions. These functions/operations may include stopping or preventing the creation of additional bearers for select devices attached to the eNodeB, stopping or preventing new devices from attaching to the eNodeB, stopping or preventing the upgrading of radio bearers of select devices, handing over select devices to a non-congested eNodeB in the same network as the congested eNodeB based on the device's location, decrease bit rates consumed by select devices by modifying the bearers of those devices, deleting the bearers of select devices to free up resources, handing over select devices to a non-congested eNodeB in a different network based on a location of the device and a service level agreement with another network,

terminating or dropping select devices (e.g., devices determined to contribute most to the congestion levels of the eNodeB), and other similar operations for mitigating or reducing the congestion level of the eNodeB.

[0066] In various embodiments, the PCRF may be configured perform these and other congestion response operations based on the priorities, categories, and sub-categories associated with the wireless devices. For example, the PCRF may cause the eNodeB (or a enforcement node) to incrementally terminate/drop wires devices based on their associated priorities, categories, and/or sub-categories until user traffic or congestion at the eNodeB return to normal (i.e., until the eNodeB returns to the "Normal" congestion state). That is, the PCRF may cause the eNodeB (or another component) to drop all secondary devices before it begins dropping primary devices. As a further example, the PCRF may cause the eNodeB to first drop secondary devices that are categorized into the "users prone to create congestion" sub-category, then drop primary devices categorized into the "users prone to create congestion" sub-category before dropping the remaining secondary devices.

[0067] The various embodiments may be implemented within a variety of communication systems, examples of which are illustrated in FIGS. **1**A-**1**E. With reference to FIG. **1**A, wireless devices **102** may be configured to transmit and receive voice, data, and control signals to and from a base station **111**, which may be a base transceiver station (BTS), NodeB, eNodeB, etc. The base station **111** may communicate with an access gateway **113**, which may include one or more of a controller, a gateway, a serving gateway (SGW), a packet data network gateway (PGW), an evolved packet data gateway (ePDG), a packet data serving node (PDSN), a serving GPRS support node (SGSN), or any similar component or combinations of the features/functions provided thereof. Since these structures are well known and/or discussed in detail further below, certain details have been omitted from FIG. **1**A in order to focus the descriptions on the most relevant features.

[0068] The access gateway **113** may be any logical and/or functional component that serves as the primary point of entry and exit of wireless device traffic and/or connects the wireless devices **102** to their immediate service provider and/or packet data networks (PDNs). The access gateway **113** may forward the voice, data, and control signals to other network components as user data packets, provide connectivity to external packet data networks, manage and store contexts (e.g. network internal routing information, etc.), and act as an anchor between different technologies (e.g., 3GPP and non-3GPP systems). The access gateway **113** may coordinate the transmission and reception of data to and from the Internet **105**, as well as the transmission and reception of voice, data and control information to and from an external service network **104**, the Internet **105**, other base stations **111**, and to wireless devices **102**.

[0069] In various embodiments, the base stations **111** and/or access gateway **113** may be coupled (e.g., via wired or wireless communication links) to a dynamic spectrum arbitrage (DSA) system configured to dynamically manage the availability, allocation, access, and use of various network resources (e.g., RF spectrum, RF spectrum resources, etc.). The DSA system is discussed in detail further below.

[0070] FIG. **1**B illustrates that wireless devices **102** may be configured to send and receive voice, data and control signals to and from the service network **104** (and ultimately the Internet **105**) using a variety of communication systems/technologies (e.g., GPRS, UMTS, LTE, cdmaOne, CDMA2000™), any or all of which may be supported by, or used to implement, the various embodiments.

[0071] In the example illustrated in FIG. **1**B, long term evolution (LTE) and/or evolved universal terrestrial radio access network (E-UTRAN) data transmitted from a wireless device **102** is received by an eNodeB **116**, and sent to a serving gateway (SGW) **118** located within the core network **120**. The eNodeB **116** may send signaling/control information (e.g., information pertaining to call setup, security, authentication, etc.) to a mobility management entity (MME) **130**. The MME **130** may request user/subscription information from a home subscriber server (HSS) **132**, communicate with other MME components, perform various administrative tasks (e.g., user authentication, enforcement of roaming restrictions, etc.), select a SGW **118**, and send authorization and administrative information to the eNodeB **116** and/or SGW **118**. Upon receiving the authorization information from the MME **130** (e.g., an authentication complete indication, an identifier of a selected SGW, etc.), the eNodeB **116** may send data received from the wireless device **102** to a selected SGW **118**. The SGW **118** may store information about the received data (e.g., parameters of the IP bearer service, network internal routing information, etc.) and forward user data packets to a policy control enforcement function (PCEF) and/or packet data network gateway (PGW) **128**.

[0072] FIG. **1**B further illustrates that general packet radio service (GPRS) data transmitted from the wireless devices **102** may be received by a base transceiver station (BTS) **106** and sent to a base station controller (BSC) and/or packet control unit (PCU) component (BSC/PCU) **108**. Code division multiple access (CDMA) data transmitted from a wireless device **102** may be received by a base transceiver station **106** and sent to a base station controller (BSC) and/or packet control function (PCF) component (BSC/PCF) **110**. Universal mobile telecommunications system (UMTS) data transmitted from a wireless device **102** may be received by a NodeB **112** and sent to a radio network controller (RNC) **114**.

[0073] The BSC/PCU **108**, BSC/PCF **110**, and RNC **114** components may process the GPRS, CDMA, and UMTS data, respectively, and send the processed data to a component within the core network **120**. More specifically, the BSC/PCU **108** and RNC **114** units may send the processed data to a serving GPRS support node (SGSN) **122**, and the BSC/PCF **110** may send the processed data to a packet data serving node (PDSN) and/or high rate packet data serving gateway (HSGW) component (PDSN/HSGW) **126**. The PDSN/HSGW **126** may act as a connection point between the radio access network and the IP based PCEF/PGW **128**. The SGSN **122** may be responsible for routing the data within a particular geographical service area, and send signaling (control plane) information (e.g., information pertaining to call setup, security, authentication, etc.) to an MME **130**. The MME **130** may request user and subscription information from a home subscriber server (HSS) **132**, perform various administrative tasks (e.g., user authentication, enforcement of roaming restrictions, etc.), select a SGW **118**, and send administrative and/or authorization information to the SGSN **122**.

[0074] The SGSN **122** may send the GPRS/UMTS data to a selected SGW **118** in response to receiving authorization information from the MME **130**. The SGW **118** may store information about the data (e.g., parameters of the IP bearer service, network internal routing information, etc.) and for-

ward user data packets to the PCEF/PGW **128**. The PCEF/PGW **128** may send signaling information (control plane) to a policy control rules function (PCRF) **134**. The PCRF **134** may access subscriber databases, create a set of policy rules and performs other specialized functions (e.g., interacts with online/offline charging systems, application functions, etc.). The PCRF **134** may then send the policy rules to the PCEF/PGW **128** for enforcement. The PCEF/PGW **128** may implement the policy rules to control the bandwidth, the quality of service (QoS), the characteristics of the data, and the services being communicated between the service network **104** and the end users.

[0075] In the various embodiments, any or all of the components discussed above (e.g., components **102-134**) may be coupled to, or included in, a DSA system configured to dynamically manage the availability, allocation, access, and use of telecommunication resources.

[0076] FIG. **1**C illustrates various logical components and communication links in an embodiment system **100** that includes an DSA system **142** and a evolved universal terrestrial radio access network (E-UTRAN) **140**. In the example illustrated in FIG. **1**C, the DSA system **142** includes a dynamic spectrum controller (DSC) **144** component and a dynamic spectrum policy controller (DPC) **146** component. The E-UTRAN **140** includes a plurality of interconnected eNodeBs **116** coupled to the core network **120** (e.g., via a connection to an MME, SGW, etc.).

[0077] In various embodiments, the DSC **144** may be included in or coupled to the E-UTRAN **140**, either as part of its core network **120** or outside of the core network **120**. In an embodiment, the DSC **144** may be coupled directly (e.g., via wired or wireless communication links) to one or more eNodeBs **116**.

[0078] The eNodeBs **116** may be configured to communicate with the DSC **144** via the Xe interface/reference point. In various embodiments, the Xe reference point between DSC and eNodeB **116** may use the DSAAP protocol, TR-069 protocol, and/or TR-192 data model extensions to support listing available resources at the eNodeB **116** and notifying the eNodeB **116** of bid/buy confirmations. The DSC **144** may be configured to communicate with the DPC **146** via the Xd interface/reference point. The Xd reference point between DSC and DPC may use the DSAAP protocol for dynamic spectrum and resource arbitrage operations. The eNodeBs **116** may be interconnected, and configured to communicate via an X2 interface/reference point, which may also use the DSAAP protocol to communicate information. The eNodeBs **116** may be configured to communicate with components in the core network **120** via the S1 interface. For example, the eNodeBs **116** may be connected to an MME **130** via the S1-MME interface and to a SGW **118** via the S1-U interface. The S1 interface may support a many-to-many relation between the MMEs **130**, SGWs **118**, and eNodeBs **116**. In embodiment, the DPC and/or DSC component may also be configured to communicate with a HSS **132** component.

[0079] The eNodeBs **116** may be configured to provide user plane (e.g., PDCP, RLC, MAC, PHY) and control plane (RRC) protocol terminations towards the wireless device **102**. That is, the eNodeBs **116** may act as a bridge (e.g., layer **2** bridge) between the wireless devices **102** and the core network **120** by serving as the termination point of all radio protocols towards the wireless devices **102**, and relaying voice (e.g., VoIP, etc.), data, and control signals to network components in the core network **120**. The eNodeBs **116** may also be configured to perform various radio resource management operations, such as controlling the usage of radio interfaces, allocating resources based on requests, prioritizing and scheduling traffic according to various quality of service (QoS) requirements, monitoring the usage of network resources, etc. In addition, the eNodeBs **116** may be configured to collect radio signal level measurements, analyze the collected radio signal level measurements, and handover wireless devices **102** (or connections to the mobile devices) to another base station (e.g., a second eNodeB) based on the results of the analysis.

[0080] The DSC **144** and DPC **146** may be functional components configured to manage the dynamic spectrum arbitrage process for sharing radio frequency and other network resources between different E-UTRANs **140**. For example, the DPC **146** component may be configured to manage the DSA operations and interactions between multiple E-UTRAN networks by communicating with DSCs **144** in the E-UTRAN network.

[0081] FIG. **1**D illustrates various logical and functional components that may be included in a communication system **101** that suitable for use in performing DSA operations in accordance with various embodiments. In the example illustrated in FIG. **1**D, the communication system **101** includes an eNodeB **116**, a DSC **144**, a DPC **146**, an MME **130**, a SGW **118**, and a PGW **128**.

[0082] The eNodeB **116** may include a DSC application protocol and congestion monitoring module **150**, an inter-cell radio resource management (RRM) module **151**, a radio bearer (RB) control module **152**, a connection mobility control module **153**, a radio admission control module **154**, an eNodeB measurement configuration and provision module **155**, and a dynamic resource allocation module **156**. Each of these modules **150-156** may be implemented in hardware, in software, or in a combination of hardware and software.

[0083] In addition, the eNodeB **116** may include various protocol layers, including a radio resource control (RRC) layer **157**, a packet data convergence protocol (PDCP) layer **158**, a radio link control (RLC) layer **159**, a medium access control (MAC) layer **160**, and a physical (PHY) layer **161**. In each of these protocol layers, various hardware and/or software components may implement functionality that is commensurate with responsibilities assigned to that layer. For example, data streams may be received in the physical layer **161**, which may include a radio receiver, buffers, and processing components that perform the operations of demodulating, recognizing symbols within the radio frequency (RF) signal, and performing other operations for extracting raw data from the received RF signal.

[0084] The DSC **144** may include an eNodeB geographic boundary management module **162**, an eNodeB resource and congestion management module **163**, a stream control transmission protocol (SCTP) module **164**, a Layer-2 (L2) buffer module **165**, and a Layer-1 (L1) buffer module **166**. The DPC **146** may include an eNodeB resource bid management module **167**, an inter-DSC communication module **168**, SCTP/DIAMETER module **169**, an L2 buffer module **170**, and a L1 buffer module **171**. The MME **130** may include a non-access stratum (NAS) security module **172**, and idle state mobility handling module **173**, and an evolved packet system (EPS) bearer control module **174**. The SGW **118** may include a mobility anchoring module **176**. The PGW **128** may include a UE IP address allocation module **178** and a packet filtering

module **179**. Each of these modules **162-179** may be implemented in hardware, in software, or in a combination of hardware and software.

[0085] The eNodeB **116** may be configured to communicate with the SGW **118** and/or MME **130** via the S1 interface/protocol. The eNodeB **116** may also be configured to communicate with the DSC **144** via the Xe interface/protocol. The DSC **144** may be configured to communicate with the DPC **146** via the Xd interface/protocol.

[0086] The eNodeB **116** may be configured to perform various operations (e.g., via modules/layers **150-161**) to provide various functions, including functions for radio resource management, such as radio bearer control, radio admission control, connection mobility control, dynamic allocation of resources to wireless devices **102** in both uplink and downlink (scheduling), etc. These functions may also include IP header compression and encryption of user data stream, selection of an MME at UE attachment when no routing to an MME **130** can be determined from the information provided by the UE, routing of user plane data towards SGW **118**, scheduling and transmission of paging messages (originated from the MME), scheduling and transmission of broadcast information (originated from the MME), measurement and measurement reporting configuration for mobility and scheduling, scheduling and transmission of public warning system (e.g., earthquake and tsunami warning system, commercial mobile alert service, etc.) messages (originated from the MME), closed subscriber group (CSG) handling, and transport level packet marking in the uplink. In an embodiment, the eNodeB **116** may be a donor eNodeB (DeNB) that is configured to perform various operations to provide additional functions, such as an S1/X2 proxy functionality, S11 termination, and/or SGW/PGW functionality for supporting relay nodes (RNs).

[0087] The MME **130** may be configured to perform various operations (e.g., via modules **172-175**) to provide various functions, including non-access stratum (NAS) signaling, NAS signaling security, access stratum (AS) security control, inter-CN node signaling for mobility between 3GPP access networks, idle mode UE reach-ability (including control and execution of paging retransmission), tracking area list management (e.g., for a wireless device in idle and active mode), PGW and SGW selection, MME selection for handovers with MME change, SGSN selection for handovers to 2G or 3G 3GPP access networks, roaming, authentication, bearer management functions including dedicated bearer establishment, support for public warning system (e.g., earthquake and tsunami warning system, commercial mobile alert service, etc.) message transmission, and performing paging optimization. The MME module may also communicate various device state and attach/detach status information to the DSC. In an embodiment, the MME **130** may be configured to not filter paging massages based on the CSG IDs towards macro eNodeBs.

[0088] The SGW **118** may be configured to perform various operations (e.g., via module **176**) to provide various functions, including mobility anchoring (e.g., for inter-3GPP mobility), serving as a local mobility anchor point for inter-eNodeB handovers, E-UTRAN idle mode downlink packet buffering, initiation of network triggered service request procedures, lawful interception, packet routing and forwarding, transport level packet marking in the uplink (UL) and the downlink (DL), accounting on user and QoS class identifier (QCI) granularity for inter-operator charging, uplink (UL) and the downlink (DL) charging (e.g., per device, PDN, and/or QCI), etc.

[0089] The PGW **128** may be configured to perform various operations (e.g., via modules **178-179**) to provide various functions, including per-user based packet filtering (by e.g. deep packet inspection), lawful interception, UE IP address allocation, transport level packet marking in the uplink and the downlink, UL and DL service level charging, gating and rate enforcement, DL rate enforcement based on APN-aggregate maximum bit rate (AMBR), etc.

[0090] The DSC **144** may be configured to perform various operations (e.g., via modules **162-166**) to provide various functions, including managing resource arbitration operations within a network (e.g., PLMN), tracking network resource listings, tracking current bids in progress, tracking executed bids, and tracking bid specific closed subscriber group (CSG) identifiers (CSG-IDs) for mobility management of lessee wireless devices **102** in lessor networks. The DSC **144** may be configured to handover wireless devices **102** from lessee network to lessor network (i.e., perform handins), and handover wireless devices **102** from lessor network back to lessee network (i.e., perform backoff).

[0091] The DSC **144** may also be configured to track congestion states of eNodeBs, select target eNodeBs for handovers, and manage traffic on lessor eNodeBs. The DSC **144** may be configured to offload users based on configured policies (e.g. offload lower priority users, offload higher priority users, offload users with specific QoS, etc.) from lessee networks to other less loaded eNodeBs **116** within a lessor network. The DSC **144** may also perform backoff operations to handover a wireless device **102** from lessor network back to the lessee network. The DSC **144** may also be configured to monitor, manage, and/or maintain historic congestion information that is collected or received from one or more eNodeBs in the system.

[0092] The DPC **146** may be configured to perform various operations (e.g., via modules **167-171**) to provide various functions, including functioning as a resource arbitrage broker between the DSCs **144** of lessor and lessee networks (e.g., PLMNs), listing resources from various lessor networks for auction, and managing the auction process. The DPC **146** may be configured to send notifications of outbid, bid win, bid cancel and bid withdrawal and bid expiry to DSCs **144**, install bid specific charging rules in the online and/or offline charging systems of lessee and lessor networks, and coordinate resource usage between DSCs **144** by acting as gateway between lessee and lessor DSCs **144**.

[0093] FIG. **1**E illustrates network components and information flows in an example communication system **103** that includes two E-UTRANs **140***a*, **140***b* interconnected by a DPC **146** configured to manage DSA operations and interactions. In the example illustrated in FIG. **1**E, each E-UTRAN **140***a*, **140***b* includes an eNodeB **116***a*, **116***b* that is outside of its core network **120***a*, **120***b*, and a DSC **144***a*, **144***b* that is inside of the core network **120***a*, **120***b*.

[0094] The DSCs **144***a*, **144***b* may be configured to communicate with the DPC **146** via Xd interface. The DSCs **144***a*, **144***b* may also be connected, directly or indirectly, to various network components in their respective core networks **120***a*, **120***b*, such as a PCRF **134**, HSS **132** and a PCEF/PGW **128** (not illustrated in FIG. **1**E). In an embodiment, one or more of the DSCs **144***a*, **144***b* may be connected directly to one or more of the eNodeBs **116***a*, **116***b*.

[0095] In addition to the above-mentioned connections and communication links, the system **103** may include additional connections/links to accommodate data flows and communications between components in different E-UTRANs (e.g., E-UTRANS **140***a* and **140***b*). For example, the system **103** may include a connection/communication link between an eNodeB **116***b* in the second E-UTRAN **140***b* to an SGW **118** in the first E-UTRAN **140***a*. As another example, the system **103** may include a connection/communication link between a SGW **118** in the second E-UTRAN **140***b* to a PGW **128** in the first E-UTRAN **140***a*. To focus the discussion of the relevant embodiments, these additional components, connections, and communication links are not illustrated in FIG. **1**E.

[0096] As is discussed in detail further below, the DSCs **144***a*, **144***b* may be configured to send information regarding the availability of spectrum resources (e.g., information received from an eNodeB, PCRF, PCEF, PGW, etc.) to the DPC **146**. This information may include data relating to current and expected future usage and/or capacity of each network or sub-network. The DPC **146** may be configured to receive and use such information to intelligently allocate, transfer, manage, coordinate, or lease the available resources of the first E-UTRAN **140***a* to the second E-UTRAN **140***b*, and vice versa.

[0097] For example, the DPC **146** may be configured to coordinate the allocation of spectrum resources to the second E-UTRAN **140***b* (i.e., lessee network) from the E-UTRAN **140***a* (i.e., lessor network) as part of the dynamic spectrum arbitrage operations. Such operations may allow a wireless device **102** that is wirelessly connected to the eNodeB **116***b* in the second E-UTRAN **140***b* via a communication link **143** to be handed off to an eNodeB **116***a* in the first E-UTRAN **140***a* so that it may use the allocated spectrum resources of the first E-UTRAN **140***a*. As part of this handoff procedure, the wireless device **102** may establish a new connection **141** to the eNodeB **116***a* in the first E-UTRAN **140***a*, terminate the wireless connection **143** to the original eNodeB **116***b*, and use the allocated resources of the first E-UTRAN **140***a* as if they are included in the second E-UTRAN **140***b*. The DSA operations may be performed so that the first DSC **144***a* is a lessor DSC for a first resource/period of time, and a lessee DSC for a second resource or another period of time.

[0098] In an embodiment, the DSA and/or handoff operations may be performed so that the wireless device **102** maintains a data connection to (or a data connection that is managed by) the original network after it is handed off. For example, DSA and/or handoff operations may be performed so that the wireless device **102** maintains a dataflow connection to a PGW **128** in the second E-UTRAN **140***b* after being handed off to the eNodeB **116***a* in the first E-UTRAN **140***a*.

[0099] FIG. **2**A illustrates an example DSA method **200** of allocating resources in accordance with an embodiment. Method **200** may be performed by a processing core in a DPC **146** component (e.g., server computing device, etc.).

[0100] In block **202**, the DPC **146** may establish a first communication link to a first DSC **144***a* in a first communication network (e.g., E-UTRAN, etc.). In block **204**, the DPC **146** may establish a second communication link to a second DSC **144***b* in a second communication network. In block **206**, the DPC **146** may determine whether radio frequency (RF) spectrum resources are available for allocation within the second communication network. This may be accomplished by using the DSAAP protocol to communicate with a DSC **144** in the second communication network via the second communication link, which may be a wired or wireless communication link. In block **208**, the DPC **146** may determine the amount of RF spectrum resources that are available for allocation. In block **210**, the DPC **146** may perform various operations to allocate all or a portion of the available RF resources of the second communication network for access and use by wireless devices **102** in the first communication network.

[0101] In block **212**, the DPC **146** may send a communication message to the first DSC **144***a* (e.g., by using the DSAAP protocol) to inform the first communication network that the use of the allocated RF spectrum resources may begin. In block **214**, the DPC **146** may record a transaction in a transaction database identifying an amount of RF spectrum resources allocated for use by the first communication network.

[0102] In block **216**, the DPC **146** may receive a communication message from the second DSC **144***b* that includes information indicating that the allocated resources have been consumed and/or requesting that the allocated resources be released. In block **218**, the DPC **146** may send a resource consumed/release message to the first DSC **144***a* to cause the first network to terminate its use of the allocated resources.

[0103] FIG. **2**B illustrates example information flows between a DPC **146** and a plurality of DSCs **144***a-d* when performing another embodiment DSA method **250** to allocate resources. In the description below, the DSA method **250** is discussed from the perspective of the DPC **146** component, and may be performed by a processing core in the DPC **146**. However, it should be understood that the DSA method **250** may be performed by processing cores in a DPC **146** component, processing cores in DSC **144***a-d* components, or a combination thereof. In addition, it should be understood that all the interactions and communications between the DPC **146** and the other components may be accomplished by DSAAP components and/or using the DSAAP protocol. As such, all such interactions and communications may be included in the DSAAP protocol.

[0104] In operation **252**, a processing core in a DPC **146** component may receive a "request for resources" communication message from a first DSC **144***a* component in a first network (e.g., E-UTRAN, etc.). It should be understood that the "request for resources" communication message and all other communication messages discussed in this application may be DSAAP messages.

[0105] The "request for resources" communication message may include information suitable for informing the DPC **146** that the first network is interested in purchasing, leasing, accessing, and/or using resources from other networks. The "request for resources" communication message may also include information suitable for identifying the types and/or amounts of resources (e.g., RF spectrum resources, etc.) that are requested by the first network, the types and capabilities of the wireless devices **102** to which the requested resources will be allocated, and other similar information.

[0106] In operations **254**, **256**, and **258** the DPC **146** may generate and send a "resource inquiry" communication message to each of a second DSC **144***b* component in a second network, a third DSC **144***c* component in a third network, and a fourth DSC **144***d* component in a fourth network, respectively. The DPC **146** may be configured to generate the "resource inquiry" communication messages to include various component, device, and resource requirements, criteria, and information. For example, the DPC **146** may generate a

"resource inquiry" communication message to include information identifying the types, capabilities, and geographic criteria of user wireless devices **102** in the first network (and other networks) to which resources are to be allocated. The geographic criteria may include a geographic location, a geographic polygon, and/or license area for a user wireless device **102** to which resources will be allocated.

[0107] In operations **260** and **262**, the DPC **146** may receive "resource inquiry response" communication messages from the second and third DSCs **144***b*, **144***c*. These "resource inquiry response" communication messages may include information identifying the availability of excess resources that comply with the requirements/criteria included in the resource inquiry messages. In operation **264**, the DPC **146** may receive another "resource inquiry response" communication message from the fourth DSC **144***d*. This "resource inquiry response" communication messages may include information indicating that the fourth network does not include resources that meet the requested requirements/criteria.

[0108] In an embodiment, as part of operations **260-264**, the DPC **146** may update a database record to identify the second and third networks as having resources available for allocation and/or to identify the fourth network as not including such resources.

[0109] In operation **266**, the DPC **146** may generate and send a "resource availability" communication message to a plurality of DSCs in a plurality of networks, including the first DSC **144***a* in the first network. The DPC **146** may be configured to generate the "resource availability" communication message to include information that is suitable for informing the networks that resources are available for allocation. In an embodiment, the DPC **146** may be configured to inform the networks that resources are available for allocation by broadcasting a communication signal that includes information suitable for informing the networks that resources are available for allocation via auction and/or an auction start time for the auction.

[0110] In operation **268**, the DPC **146** may receive a "resource reservation request" communication message from the first DSC **144***a*. The received "resource reservation request" communication message may include information suitable for informing the DPC **146** that the first network intends to participate in the auction and/or bid on at least a portion of the available resources.

[0111] In operations **270** and **272**, the DPC **146** may send the "resource reservation request" communication message to the second and third DSCs **144***b*, **144***c*, respectively. The "resource reservation request" communication message may include information suitable for causing the second and third DSCs **144***b*, **144***c* to reserve all or a portion of their available resources for allocation and use by other networks.

[0112] In operations **274** and **276**, the DPC **146** may receive a "resource reservation response" communication message from each of the second and third DSCs **144***b*, **144***c*. The "resource reservation response" messages may include information suitable for informing the DPC **146** that the requested resources that have been reserved and/or information suitable for identifying the reserved resources.

[0113] Optionally, in operation block **278**, the DPC **146** may pool the reserved resources for allocation and use by wireless devices **102** in other networks (e.g., the first network). For example, the DPC **146** may combine a block of spectrum reserved in the second network with a block of spectrum reserved in the third network. As another example, the DPC **146** may pool the resources available in the first and fourth channels of a block of spectrum reserved in the second network.

[0114] In operation **280**, the DPC **146** may receive "resource bid" communication messages from a plurality of networks, including from the first DSC **144***a* in the first network. Each "resource bid" communication message may include a bid or offer for accessing, using, leasing, and/or purchasing a resource, as well as other related bid information (e.g., price, requested allocation/access methods, etc.). As part of operation **280**, the DPC **146** may determine whether the received resource bids comply with the policies and rules of the DSA system and/or with requirements set forth by the networks offering the resources for allocation (e.g., meet the minimum asking price, etc.).

[0115] In operation **282**, the DPC **146** may accept the bid/offer from the first network in response to determining that the resource bid received from the first network complies with the policies/rules of the DSA system and with requirements set forth by the resource offering network (e.g., offers a monetary amount for the use of all or a portion of the resources in the pool of available resources that is greater than or equal to a minimum amount specified by the second network). Also in operation **282**, the DPC **146** may generate and send a "bid acceptance" communication message to the first DSC **144***a*.

[0116] In operation **284**, the DPC **146** may allocate the resources of the second network for access and used by wireless devices **102** in the first network by sending an "assign resources request" communication message to the second DSC **144***b*. That is, in operation **284**, the DPC may determine that the portion of the resources (e.g., in the pool of available resources) won by the first DSC **144***a* are fully available via the second network, and in response, only send the assign resources request message to the second network.

[0117] In operation **286**, the DPC **146** may receive a "resources allocated" communication message from the second DSC **144***b*. In operation **288**, the DPC **146** may send the "resources allocated" communication message to the first DSC **144***a* to inform the first network that the resources have been allocated for access and used by its wireless devices **102** and/or that the use of the allocated resources may begin. In operation block **290**, the DPC **146** may record a transaction in a transaction database identifying these resources as being allocated for access and use by the first network.

[0118] In operation **292**, the DPC **146** may receive a "release resources" communication message from the second DSC **144***b* that includes information indicating that the allocated resources have been consumed and/or information suitable for requesting that the allocated resources be released. In operation **294**, the DPC **146** may send a resource consumed/release message to the first DSC **144***a* to cause the first network to terminate its use of the allocated resources.

[0119] FIGS. **3-7** illustrate an embodiment DSA method **300** for allocating and accessing resources in a communication system that includes a DPC **146** component, two DSC **144***a*, **144***b* components, and wireless devices **102**. All or portions of DSA method **300** may be performed by processing cores in a DPC **146**, DSCs **144***a-b*, and/or wireless device **102**. In the various embodiments, any of all of the interactions and communications between the components **146**, **144***a*, **144***b*, and **102** may be accomplished or facilitated by DSAAP

components and/or using the DSAAP protocol. As such, all such interactions and communications may be included in the DSAAP protocol.

[0120] With reference to FIG. **3**, in block **302**, a first DSC **144***a* in a first network may monitor user traffic (e.g., call and data traffic, etc.) as compared to the total spectrum resources available to the first network. In block **304**, the first DSC **144***a* may generate a resource status report based on a result of its monitoring, record/store the resource status report in memory, and send a resource status report to the DPC **146** via a resources status report communication message. In determination block **306**, the first DSC **144***a* may determine, based on the received resource status reports, whether additional resources are required (and/or whether there is a high probability that additional resources will be required in the near future) to provide adequate service to the existing wireless devices **102** in the first network. In response to determining that additional resources are required (i.e., determination block **306**="Yes"), in block **308**, the first DSC **144***a* may send a "request for resources" communication message to the DPC **146**. In response to determining that additional resources are not required (i.e., determination block **306**="No"), the first DSC **144***a* may continue monitoring user traffic and/or perform other DSC operations in block **302**.

[0121] In block **310**, a second DSC **144***b* in a second network may monitor user traffic as compared to the total spectrum resources available to the second network, generate resource status reports, and/or perform any or all of the DSC operations discussed in this application. In determination block **312**, the second DSC **144***b* may determine whether there is an excess amount of resources available in the second network. In response to determining that there are no excess resources available in the second network (i.e., determination block **312**="No"), in block **310**, the second DSC **144***b* may continue monitoring user traffic and/or performing other DSC operations.

[0122] In response to determining that there is an excess amount of resources available in the second network (i.e., determination block **312**="Yes"), in block **314**, the second DSC **144***b* may mark, designate, or allocate all or portions of its excess resources for access and use by other networks (e.g., the first network, etc.). In block **316**, the second DSC **144***b* may generate a resource allocation report, and send the generated resource allocation report to the DPC **146** (e.g., via a resource communication message). The DSC **144***b* may be configured to generate the resource allocation report to include information identifying the resources (or portions or amounts of resources) that are available for allocation and/or that have been marked, designated, or allocated by the second network.

[0123] In block **320**, the DPC **146** may receive various resource status and allocation reports from DSCs **144** in many different networks, including the first and second DSCs **144***a*, **144***b* in the first and second networks. These reports may include information identifying various characteristics, criteria, requirements, and conditions of the networks and their components, such as the ratio of the detected user traffic to the total available spectrum resources, the amount of resources that are required by a network, the amount of resources that are available for allocation in a network, the types and capabilities of the wireless devices **102** that will use the allocated resources, system requirements that must be met before the wireless devices **102** access the allocated resources, network rules and policies with respect to access and use of resources, and other similar information.

[0124] In block **322**, the DPC **146** may store the received reports (e.g., resource status reports, resource allocation reports, etc.) in memory (e.g., a non-volatile memory). In block **324**, the DPC **146** may receive a request for resources from DSCs **144** in different networks, including the first DSC **144***a* in the first network. In block **326**, the DPC **146** may use the received/stored information (e.g., information received in requests for resources, resource allocation reports, resource status reports, etc.) to identify and select the most suitable/best available network from which the first network may lease or purchase additional resources. In the example illustrated in FIG. **3**, the DPC **146** identifies and selects the second network as the most suitable network to provide resources to the first network.

[0125] In block **328**, the DPC **146** may send a resource inquiry communication message to the second DSC **1144***b*. In block **330**, the second DSC **1144***b* may receive the resource inquiry communication message. In block **332**, the second DSC **1144***b* may determine the availability, amounts, and/or quantity of the excess resources that are marked, designated, or allocated by the second network. In block **334**, the second DSC **1144***b* may generate and send a "resource inquiry response" communication message to the DPC **146**. The second DSC **1144***b* may generate resource inquiry response to include information suitable for use in identifying the availability and quantity of the resources that are marked, designated, or allocated for access and use by other networks (e.g., the first network). In block **336**, the DPC **146** may receive the "resources inquiry response" communication message from the second DSC **1144***b*, and in response, perform the operations of determination block **400** illustrated in FIG. **4**.

[0126] With reference to FIG. **4**, in determination block **400**, the DPC **146** may determine whether resources are available based on the data (e.g., resources inquiry response message) received from the second DSC **144***b* in the second network. For example, the DPC **146** may determine that the identified resources are not available in response to determining that all or a portion of the resources were purchased or won by other bidders before they were reserved.

[0127] In response to determining that the resources are not available (i.e., determination block **400**="No"), in block **402**, the DPC **146** may send a "no resources available" communication message to the first DSC **144***a* in the first network. In block **404**, the first DSC **144***a* may receive the "no resources available" communication message. In block **406**, the first DSC **144***a* may search (e.g., via the DPC **146**) for other available resources, request resources from a different network, request different resources, terminate connections or communication sessions with users to free-up resources, or perform other similar operations to manage network traffic and congestion in the first network.

[0128] In response to determining that the resources are available (i.e., determination block **400**="Yes"), in block **408**, the DPC **146** may send a "resources available" communication message to the first DSC **144***a*. The resources available message may include information that may be used by the first DSC **144***a* to determine the quality and quantity of resources in the second network that may be used by wireless devices **102** in the first network.

[0129] In block **410**, the first DSC **144***a* may receive the resources available communication message sent from the

DPC **146**. In block **412**, the first DSC **144***a* may determine the amount/quantity of resources that the first network requires and/or will attempt to acquire, and send this and other resource information to the DPC **146** in a "request resources" communication message.

[0130] In block **414**, the DPC **146** may receive the "request resources" message from the first DSC **144***a*. In block **416**, the DPC **146** may use information included in received message to generate and send a "reserve resources request" communication message to the second DSC **144***b* in the second network.

[0131] In block **418**, the second DSC **144***b* may receive the "reserve resource request" message from the DPC **146**. In block **420**, the second DSC **144***b* may use the information included in the received "reserve resources request" message to reserve the requested quantity of allocated resources for access and use by components in other networks. In block **422**, the second DSC **144***b* may send a "resource reserved" communication message to the DPC **146** to confirm that the requested quantity of resources has been reserved and/or to identify the reserved resources.

[0132] In block **424**, the DPC **146** may receive the "resource reserved" communication message from the second DSC **144***b*. In block **426**, the DPC **146** may offer the reserved resources for auction and/or begin accepting resource bids on the reserved resources.

[0133] FIG. **5** illustrates a bidding procedure of the DSA method **300** that may be performed after the DPC **146** offers the reserved resources for auction and/or begins accepting resource bids on the reserved resources (e.g., after performing the operations of block **426** illustrated in FIG. **4**).

[0134] With reference to FIG. **5**, in block **500**, the first DSC **144***a* in the first network may negotiate access to the reserved resources of second network by sending a resource bid (e.g., via a communication message) to the DPC **146**. In block **502**, the DPC **146** may receive the resource bid from the first DSC **144***a*.

[0135] In determination block **504**, the DPC **146** may determine whether the received resource bid is to be accepted, which may be accomplished by determining whether the resource bid complies with the policies and rules of the DSA system and the requirements of the second network (e.g., is greater than a minimum amount, etc.). In response to determining that the resource bid received from the first DSC **144***a* is to be accepted (i.e., determination block **504**="Yes"), in block **506**, the DPC **146** may send an "accept bid" communication message to the first DSC **144***a*. In block **508**, the first DSC **144***a* may receive the "accept bid" message and wait to receive resource access instructions. In block **510**, the DPC **146** may send an "assign resources" communication message to the second DSC **144***b* in the second network.

[0136] In block **512**, the second DSC **144***b* may receive the "assign resources" communication message from the DPC **146**. In block **514**, the second DSC **144***b* may use the information included in the received "assign resources" message to assign all or portions of its reserved resources for access and use by components in the first network. In block **516**, the second DSC **144***b* may generate a "resources access" communication message that includes information (e.g., access parameters, etc.) that may be used by a wireless device **102** (i.e., in the first network) to access the assigned resources, and the send the "resources access" message to the DPC **146**. In block **518**, the second DSC **144***b* may perform various operations to prepare for establishing a communication session/link to wireless device **102** in the first network, such as by configuring or preparing to receive a voice or data call.

[0137] In block **522**, the DPC **146** may receive the "resources access" communication message from the second DSC **144***b*, and relay the resources access message to the first DSC **144***a*. In block **524**, the first DSC **144***a* may receive the "resources access" message from the DPC **146**. The received "resource access" message may include access parameters that may be used by the wireless devices **102** to access the allocated resources of the second network. In block **526**, the first DSC **144***a* may send access parameters to wireless devices **102** that have communication sessions with the first network and/or to the wireless devices **102** that the first network has designated/marked for migration to other networks.

[0138] In block **528**, the wireless devices **102** may receive the access parameters of second network from the first DSC **144***a*. In blocks **530** and **520**, the wireless devices **102** and/or second DSC **142***b* may perform various operations to establish a communication session/link between the wireless devices **102** and the second network. The second DSC **144***b* may then perform the operations of block **700** illustrated in FIG. **7** and discussed further below.

[0139] As mentioned above, in determination block **504**, the DPC **146** may determine whether the resource bid received from the first DSC **144***a* is to be accepted. In response to determining that the resource bid received from the first DSC **144***a* is not to be accepted (i.e., determination block **504**="No"), the DPC **146** may perform the operations of block **600** illustrated in FIG. **6**.

[0140] With reference to FIG. **6**, in block **600**, the DPC **146** may send a "rejected bid" communication message to the first DSC **144***a*. In block **602**, the first DSC **144***a* may receive the "rejected bid" message from the DPC **146**. In determination block **604**, the first DSC **144***a* may determine whether the first network will/should rebid for the resources. In response to determining that the first network will/should rebid for the resources (i.e., determination block **604**="Yes"), in block **606**, the first DSC **144***a* may send a new resource bid (e.g., in a resource bid communication message) to the DPC **146**.

[0141] In block **608**, the DPC **146** may receive the new resource bid (or rebid) from the first DSC **144***a*. In determination block **610**, the DPC **146** may determine whether to accept the new resource bid, such as by determining whether the new resource bid complies with the policies and rules of the DSA system and the requirements of the second network. In response to determining that the new resource bid is to be accepted (i.e., determination block **610**="Yes"), the DPC **146** may perform the operations of block **506** illustrated in FIG. **5**. In response to determining that the new resource bid is to not be accepted (i.e., determination block **610**="No"), the DPC **146** may perform the operations of block **600**.

[0142] In response to determining that the first network should rebid for the resources (i.e., determination block **604**="No"), in block **612**, the first DSC **144***a* may send a "cancel resource request" communication message to the DPC **146**. In block **614**, the DPC **146** may receive the "cancel resource request" message from the first DSC **144***a*. In block **616**, the DPC **146** may send a "release of resources" communication message to the second DSC **144***b*.

[0143] In block **618**, the second DSC **144***b* may receive the "release of resources" message from the DPC **146**. In block **620**, the second DSC **144***b* may release the reserved resources so that they may be used by other networks. The second DSC **144***b* may then report the status of the allocated resources to

DPC **146**, which may be accomplished by performing the operations of block **316**, which is illustrated in FIG. **3** and discussed above.

[0144] FIG. **7** illustrates settlement procedure of the DSA method **300** that may be performed after second network provides access to the secondary user wireless devices **102** in the first network (i.e., after performing the operations of block **520** illustrated in FIG. **5**).

[0145] In block **700**, the second DSC **144***b* may send invoices and payment instructions relating to the use of allocated resources by the first network to the DPC **146**. In block **704**, the DPC **146** may relay the received invoice and payment instructions to the first DSC **144***a*. In block **706**, the first DSC **144***a* may receive the invoices and payment instructions, and settle the charges with the second network in block **718**.

[0146] Optionally or alternatively, in block **708**, the second DSC **144***b* may send usage parameters and payment instructions to the DPC **146**. In block **710**, the DPC **146** may receive the usage parameters and payment instructions from the second DSC **144***b*. In block **712**, the DPC **146** may create an invoice for the access and use of the resources. In block **714**, the DPC **146** may send the invoice to the first DSC **144***a* in the first network. In block **716**, the first DSC **144***a* may receive the invoice and payment instructions, and perform various operations to settle the charges with second network in block **718**.

[0147] In the various embodiments, the DPC **146** and DSC **144** components may be configured to communicate via an interface, which may be implemented in, or provided via, a dynamic spectrum allocation application part (DSAAP) protocol/module/component that is defined over the Xe and/or Xd reference points. The DSAAP may allow, facilitate, support, or augment communications between the DPC **146** and DSC **144** so as to improve the efficiency and speed of the DSA system and telecommunication network. In various embodiments, all or portions of the DSAAP module/component may be included in a DPC **146** component, a DSC **144** component, in a component that is independent of the DPC **146** and DSC **144** components, or any combination thereof. The DSAAP module/component may allow these and other DSA components to communicate information using the DSAAP protocol.

[0148] For example, the DSAAP may allow the DPC **146** and DSC **144** components to communicate specific information and/or perform operations that together provide various functions, including a DSC registration function, resource availability advertisement function, bidding and allocation of resources functions, handing off lessee users to lessor network function, backoff from lessor networks function, error handling function (e.g., reporting of general error situations for which function specific error messages are not defined, etc.), DSC de-registration function, error indication function, DSC bidding success and failure indication functions, and DSC resource allocation withdrawal function. In various embodiments, these functions may be provided, implemented, or accomplished by configuring the DPC **146** and/or DSC **144** components to perform one or a combination of the DSAAP methods discussed below with reference to FIGS. **8**A-**17**B. Using the DSAAP protocol and performing the DSAAP methods may include communicating via one or more DSAAP messages.

[0149] In various embodiments, the DSAAP messages used to communicate information between the DSC **144** and DPC **146** may include a DSC REGISTER REQUEST message, DSC REGISTER ACCEPT message, DSC REGISTER REJECT message, DSC DE-REGISTER message, DSC RESOURCE REGISTER REQUEST message, DSC RESOURCE REGISTER ACCEPT message, DSC RESOURCE REGISTER REJECT message, AVAILABLE BIDS REQUEST message, AVAILABLE BIDS RESPONSE message, AVAILABLE BIDS REJECT message, DSC BID REQUEST message, DSC BID ACCEPT message, DSC BID REJECT message, DSC BID OUTBID message, DSC BID WON message, DSC BID LOST message, DSC BID CANCELLED message, DSC BUY REQUEST message, DSC BUY ACCEPT message, DSC BUY REJECT message, DSC RESOURCES ALLOCATED message, DSC RESOURCES WITHDRAWN message, and/or DSC BACKOFF COMMAND message. Each of these messages may include, or may be associated with, criticality information, presence information, range information, and assigned criticality information. These messages and their contents are discussed in detail further below.

[0150] In various embodiments, the DSAAP methods may be performed in a DSA system that includes a first DSC server in a first telecommunication network (e.g., a lessee network), a second DSC server in second telecommunication network (e.g., a lessor network), and a DPC server that is outside of the first and second telecommunication networks. The first DSC may include first DSC processor coupled to the DPC via a first communication link, and the second DSC may include a second DSC processor coupled to the DPC via a second communication link. The second DSC may be coupled to an eNodeB in the second telecommunication network via third communication link. The first and second communication links may be defined over the Xd interface, and the third communication link is defined over the Xe interface.

[0151] FIGS. **8**A through **8**C illustrate an embodiment DSAAP registration method **800** for registering a DSC **144** component with a DPC **146** so as to allow the DPC **146** to provide various services to the DSC **144** (e.g., advertizing a lessor DSC's **144** resources for bidding, allowing a lessee DSC **144** to bid for resources provided by other networks, etc.). In the examples illustrated in FIGS. **8**A through **8**C, the DSAAP registration method **800** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component. The operations DSAAP registration method **800** may be performed after, or in response to the DSC **144** or DPC **146** detecting that, an XE signaling transport or communication link has been established.

[0152] In operation **802** illustrated in FIGS. **8**A through **8**C, the DSC **144** may initiate DSAAP registration method **800** by generating and sending a DSC REGISTER REQUEST message to the DPC **146**. In an embodiment, the DSC **144** may be configured to generate and/or send the DSC REGISTER REQUEST message in response to determining that it requires services from the DPC **146**. For example, the DSC **144** may be configured to generate the DSC REGISTER REQUEST message in response to determining that its corresponding network (i.e., the network represented by the DSC) includes excess resources that may be allocated to other networks. As another example, the DSC **144** may be configured to generate the DSC REGISTER REQUEST message in response to determining that its newtork requires additional resources to provide adequate service to its existing wireless devices **102** in view of the current or expected future user traffic, network congestion, etc.

[0153] In various embodiments, the DSC **144** may be configured to generate the DSC REGISTER REQUEST message to include any or all of a message type information element (IE), a message ID IE, a DSC identity IE, a DSC Internet protocol (IP) address IE, a DSC type IE, a DSC PLMN-ID IE, PLMN type IE, and DSC resource update timer IE. The DSC PLMN-ID IE may include a PLMN ID that is suitable for use in identifying the network (e.g., E-UTRAN) that is associated with, or represented by, the DSC **144**. The PLMN type IE may include information that is suitable for use in determining the type of network (e.g., public safety, commercial, etc.) that is represented by the DSC **144**. The DSC IP address IE may include the IP address of a DSC **144** that is responsible for managing, maintaining, or providing the XE interface of the DSAAP.

[0154] In operation block **804** illustrated in FIGS. **8**A and **8**B, the DPC **146** may perform various registration operations (i.e., authenticating the DSC, storing DSC identifier information in memory, etc.) to register the DSC **144** with the DPC **146**. In an embodiment, as part of these registration operations, the DPC **146** may overwrite/override an existing registration with a new registration, such as in response to receiving a duplicate DSC REGISTER REQUEST message (i.e. for an already registered DSC identified by the same unique DSC identity).

[0155] In operation block **806** illustrated in FIG. **8**A, the DPC **146** may determine that the registration operations were successful. In operation **808**, the DPC **146** may generate and send a DSC REGISTER ACCEPT message to the DSC **144** to indicate the acceptance and registration of the DSC **144**. In various embodiments, the DPC **146** may generate the DSC REGISTER ACCEPT message to include any or all of a message type information element (IE), a message ID IE, a DPC ID IE, a XEh signaling transport network layer (TNL) address IE, and a tunneling information IE. The XEh signaling TNL address IE may include an address value that is suitable for use in establishing to transport layer session. The tunneling information IE may include information that may used to encapsulate a different payload protocol, establish a secured communication through an untrusted or unverified network, carry a payload over an incompatible delivery-network, and/or to perform other similar tunneling operations.

[0156] To support XEh connectivity via/to the DPC **146**, in operation block **810**, the DSC **144** may use the address value included in the XEh signaling TNL address IE of the DSC REGISTER ACCEPT message establish a transport layer session. In an embodiment, the DSC **144** may be configured to establish the transport layer session in response to determining that the DSC REGISTER ACCEPT message includes an address value in the XEh signaling TNL address information element. In an embodiment, the DSC **144** may be configured to determine that the XEh connectivity via/to the DPC **146** is not supported or not required in response to determining that the XEh signaling TNL address information element is not present, null, empty, or not valid.

[0157] With reference to FIG. **8**B, in operation block **812**, the DPC **146** may determine that the registration operations performed as part of operation **804** failed. The DPC **146** may determine that registration failed in response to detecting any of a variety of conditions/events, including the failure to authenticate or authorize the DSC, network or component overload, DSC parameter mismatch, etc. In operation **814**, the DPC **146** may generate and send a DSC REGISTER REJECT message to the DSC **144** to inform the DSC **144** that the registration failed and/or that the DPC **146** cannot register the DSC **144**. In various embodiments, the DPC **146** may generate the DSC REGISTER REJECT message to include any or all of a message type information element (IE), a message ID IE, a cause IE, a criticality diagnostics IE, and a backoff timer IE. The cause IE may include information suitable for identifying a specific reason for the failure (e.g., overloaded, etc.) or for indicating that the reason for the failure is not known or is unspecified.

[0158] In operation block **816**, the DSC **144** may perform various registration failure-response operations based on the information included in the received REGISTER REJECT message. For example, the DSC **144** may wait for a duration indicated in the backoff timer IE of the received REGISTER REJECT message before reattempting registration with that same DPC **146** in response to determining that the value of the cause IE in the received REGISTER REJECT message is set to "overload."

[0159] With reference to FIG. **8**C, in operation block **852**, the DSC **144** may start a register response timer in response to sending a DSC REGISTER REQUEST message to the DPC **146** (e.g., as part of operation **802**). In operation block **854**, the DSC **144** may determine that the register response timer expired before the DSC **144** received a DSC REGISTER RESPONSE message. In operation **856**, the DSC **144** may resend the DSC REGISTER REQUEST message to the DPC **146** in response to determining that the timer expired before it received a corresponding DSC REGISTER RESPONSE message. In operation block **858**, the DSC **144** may restart or reset the register response timer. In operation **860**, the DPC may send a DSC REGISTER RESPONSE message to the DSC **144**. In operation block **862**, the DSC **144** may stop the register response timer in response to receiving the DSC REGISTER RESPONSE message.

[0160] FIGS. **9**A and **9**B illustrate a DSAAP advertizing method **900** for advertizing resources that are available for bidding/buying so as to allow the DPC **146** to store, organize, and/or make those resources available for bidding/allocation via a financial brokerage platform. In the examples illustrated in FIGS. **9**A and **9**B, the DSAAP advertizing method **900** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component.

[0161] In operation block **902** illustrated in FIGS. **9**A and **9**B, the DSC **144** may determine that there are resources available for allocation within cells serviced by that DSC **144**. In operation block **904**, the DSC **144** may generate and send a DSC RESOURCE REGISTER REQUEST message to the DPC **146**. In various embodiments, the DSC **144** may generate the DSC RESOURCE REGISTER REQUEST message to include any or all of a message type information element (IE), a message ID IE, a DSC identity IE, a DSC type IE, a PLMN-ID list IE, resource availability IE, resource availability start time IE, a data bandwidth IE, a list of grids IE, a bid or buy IE, a minimum bid amount IE, resource availability end time IE, a time of the day IE, a time duration IE, megabits per second (MBPS) IE, and a cell identity IE.

[0162] The DSC identity IE may include information that may be used by the DPC **146** to determine the identity of DSC **144**. For example, the DSC identity IE may include a DSC pool ID, DSC instance information, and a PLMN ID of the network that the DSC is managing or representing. The DSC pool ID may be a unique identifier of a pool of available

resources and/or may be the same as or similar to MME pool IDs and MME IDs in 3GPP EPC architecture.

[0163] The message ID IE may include a message identifier for the specific DSC RESOURCE REGISTER REQUEST message sent from the DSC **144**. The DSC **144** and DPC **146** may be configured to use the message ID IE as a sequence number to identify and correlate DSC RESOURCE REGISTER REQUEST, DSC RESOURCE REGISTER ACCEPT and/or DSC RESOURCE REGISTER REJECT messages.

[0164] The resource availability IE may include information suitable for use by the DPC **146** in determining the PLMN ID of the network that is advertising resources for allocation and use by other networks. The DPC **146** may be configured to receive, store, and/or maintain resource availability IEs for multiple DSCs and/or for multiple different networks (i.e. different PLMN IDs). As such, each resource availability IE may include information suitable for identifying one or more of the networks that are advertising resources.

[0165] The time of the day IE may include information suitable for use by the DPC **146** in determining the time of the day that the DSC **144** transmitted the DSC RESOURCE REGISTER REQUEST message. The time duration IE may include information that is suitable for use in determining a time period during which the resources are to be made available for bidding or buying.

[0166] The data bandwidth IE may include information suitable for use in determining the available bandwidth (e.g., in MBPS) for the time duration specified in the optional time duration IE. The DPC **146** may determine that the bandwidth specified in the MBPS IE is to be made available until that bandwidth is consumed by the winning bidder or buyer in response to determining that the time duration IE is not included in the received DSC RESOURCE REGISTER REQUEST message (or in response to determining that the time duration IE does not include a valid value).

[0167] The list of grids IE may include information suitable for use in determining grid identifiers for the locations of the network bandwidth that is to be made available for bidding or buying. The cell identity IE may include information suitable for use in determining the individual cells within each grid (identified by grid ID and cell ID) that have available resources offered for bidding or buying as part of the offer in the DSC RESOURCE REGISTER REQUEST message. The minimum bid amount IE may include a monetary amount in a denomination or currency, such as in United States Dollars (USD).

[0168] In operation block **906** illustrated in FIG. **9**A, the DPC **146** may accept the DSC's **144** resources for bidding. In operation **908**, the DPC **146** may generate and send a DSC RESOURCE REGISTER RESPONSE or DSC RESOURCE REGISTER ACCEPT message to the DSC **144** to acknowledge that the resources were accepted. In various embodiments, the DPC **146** may generate the DSC RESOURCE REGISTER message to include any or all of a message type information element (IE), a bid ID IE, and a message ID IE. The message ID IE may include the same message identifier value that is included in the received DSC RESOURCE REGISTER REQUEST message. The DPC **146** and/or DSC may be configured to use the value of the message ID IE to identify and correlate the DSC RESOURCE REGISTER REQUEST and DSC RESOURCE REGISTER ACCEPT messages. In operation block **910**, the DPC **146** may store, organize, and/or make the network resources available for bidding or buying via the financial brokerage platform.

[0169] In operation **912** illustrated in FIG. **9**B, the DPC **146** may reject the DSC RESOURCE REGISTER REQUEST message and/or reject for bidding the resources identified in the received DSC RESOURCE REGISTER REQUEST message. The DPC **146** may reject the message/resources for a variety of reasons and/or in response to detecting any of a variety of events or conditions. For example, the DPC **146** may reject the resources in response to determining that the DPC **146** is not accepting resources from any operator, is not accepting resources for the specific operator identified in the received message, is not accepting the resources identified in the message, that the DPC is overloaded, that there is insufficient memory to store and service the resources available for bidding, etc. The DPC **146** may also reject the resource available message in response to determining that an administrator of the DPC **146** has disabled further bidding from the specific PLMN ID included in the DSC RESOURCE REGISTER REQUEST message, from all the networks (e.g., all the PLMN IDs), etc.

[0170] In operation **914** illustrated in FIG. **9**B, the DPC **146** may generate and send a DSC RESOURCE REGISTER REJECT message to the DSC **144**. In various embodiments, the DPC **146** may generate the DSC RESOURCE REGISTER REJECT message to include any or all of a message type information element (IE), a message ID IE, a cause IE, and a criticality diagnostics IE. The DPC **146** may also generate the DSC RESOURCE REGISTER REJECT message to include a message ID IE that includes a value that is the same as the message identifier included in the DSC RESOURCE REGISTER REQUEST message received from DSC **144**. The DPC **146** and/or DSC **144** may be configured to use the value of the message ID IE to identify and correlate the DSC RESOURCE REGISTER REQUEST and DSC RESOURCE REGISTER REJECT messages.

[0171] In operation block **916**, the DSC **144** may perform various resource registration failure response operations based on information included in the received DSC RESOURCE REGISTER REJECT message. For example, the DSC **144** may use the information included in the DSC RESOURCE REGISTER REJECT message to determine whether to reattempt resource registration with the DPC **146**, attempt to register the resources with another DPC, reattempt the registration with different resources, or perform any of the other DSC operations discussed in this application.

[0172] FIGS. **10**A and **10**B illustrate a DSAAP method **1000** for communicating a list of available resources in accordance with an embodiment. DSAAP method **1000** may be performed to inform lessee networks of the resource bids or resources that are available for bidding/buying. In the examples illustrated in FIGS. **10**A and **10**B, the DSAAP method **1000** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component. In an embodiment, a lessee DSC **144** may be configured to perform DSAAP method **1000** to retrieve/receive a list of available resources prior to that DSC **144** bidding on, or requesting to lease or purchase, resources from the DPC **146**.

[0173] In operation **1002** illustrated in FIGS. **10**A and **10**B, a lessee DSC **144** may generate and send an AVAILABLE BIDS REQUEST message to the DPC **146** to request information on the resource bids that are available for allocation from lessor network(s) for bidding or buying. In various embodiments, the lessee DSC **144** may generate the AVAILABLE BIDS REQUEST message to include any or all of a

sequence number information element (IE), a message type IE, a PLMN list IE that includes one or more PLMN ID IEs, a grid ID list IE that includes one or more Grid ID IEs.

[0174] In an embodiment, the lessee DSC **144** may be configured to request specific resources from a specific network by generating the AVAILABLE BIDS REQUEST message to include the PLMN ID of the desired network, which may be included in the PLMN ID IE of the PLMN list IE in the AVAILABLE BIDS REQUEST message.

[0175] In an embodiment, the lessee DSC **144** may be configured to request resources from any available network by not populating the PLMN list IE in the generated AVAILABLE BIDS REQUEST message and/or by generating the AVAILABLE BIDS REQUEST message to not include a PLMN list IE and/or PLMN ID value.

[0176] In an embodiment, the lessee DSC **144** may be configured to request resources from a specific grid within a lessor network by generating the AVAILABLE BIDS REQUEST message to include the grid IDs of the desired grids, which may be included in the grid ID IE of the grid ID list IE in the AVAILABLE BIDS REQUEST message.

[0177] In an embodiment, the lessee DSC **144** may be configured to request resources from any or all grids within a specified PLMN ID in PLMN ID IE grid by not populating the grid ID list IE in the generated AVAILABLE BIDS REQUEST message and/or by generating the AVAILABLE BIDS REQUEST message to not include a grid ID.

[0178] In operation block **1004** illustrated in FIGS. **10**A and **10**B, the DPC **146** may determine whether the PLMN ID(s) and grid ID(s) included in the received AVAILABLE BIDS REQUEST message are valid. If the PLMN ID(s) and grid ID(s) are incorrect, in operation block **1005**, the DPC **146** may determine a reason code for the error/incorrect values. In operation block **1006**, the DPC **146** may determine whether there are resources/bids available for each grid identified in the received AVAILABLE BIDS REQUEST message or for all the available grids (e.g., when the grid ID list IE in the received AVAILABLE BIDS REQUEST message not include valid values).

[0179] In operation **1008** illustrated in FIG. **10**A, the DPC **146** may generate and send an AVAILABLE BIDS RESPONSE message to the DSC **144**. The DPC **146** may be configured to generate the AVAILABLE BIDS RESPONSE message to include any or all of a message type information element (IE), a message ID IE, a DSC identity IE, a PLMN-ID grid cell bid info list IE, a sequence number IE, a PLMN list IE that includes one or more PLMN ID IEs, and a grid list IE. In an embodiment, the PLMN list IE and grid list IE may be included in the PLMN-ID grid cell bid info list IE. In an embodiment, the grid list IE may include one or more cell ID list IEs that include one or more cell ID IEs.

[0180] In various embodiments, the DPC **146** may generate the AVAILABLE BIDS RESPONSE message to also include any or all of an absolute radio-frequency channel number (ARFCN) IE, a channel bandwidth IE, a megabit or megabyte IE for identifying total available bandwidth, a MBPS IE for identifying the peak data rate for the resource, a resource available time IE, a resource expiration time IE, a bid/buy IE, a bid/buy expiry time IE, a minimum bid amount IE, and a buy price IE. The DPC **146** may generate the AVAILABLE BIDS RESPONSE message to include such information for each PMLN, each resource, each grid, and/or each cell identified in the message.

[0181] In an embodiment, the DPC **146** may be configured to generate the AVAILABLE BIDS RESPONSE message to include the list of PLMN ID, lists of grid ID(s) within each PLMN, and the available resources/bids within each grid in response to determining that there are bids for resources available for auction.

[0182] In an embodiment, the DPC **146** may be configured to generate the AVAILABLE BIDS RESPONSE message to include the message type and sequence number IEs (or valid values for these IEs) in response to determining that there no resources/bids for resources available for auction by that DPC **146** for the relevant networks/PLMN IDs. In an embodiment, the DPC **146** may be configured to generate the AVAILABLE BIDS RESPONSE message to include a sequence number IE having the same value as in the sequence number IE included in the received AVAILABLE BIDS REQUEST message. In an embodiment, the DSC **144** may be configured to use the sequence number IEs in these request and response messages to correlate the messages.

[0183] In an embodiment, the DPC **146** may be configured to generate the AVAILABLE BIDS RESPONSE message to include a PLMN list IE that includes a PLMN ID and grid ID list IE. The grid ID list IE may include a list of cells available for auction within the grid. The cell ID list IE may include a cell ID, and for each cell, the ARFCN, channel bandwidth, total available bandwidth, peak data rate allowed, the time of day (e.g., in UTC) when the resources are available and when they expire/end, whether it's a bid or buy type auction, minimum bid amount or buy price, bid expiry time (e.g., in UTC), and other similar information.

[0184] In operation block **1010**, the DSC **144** may use the information included in the AVAILABLE BIDS RESPONSE message to identify the resources that are available for bidding, determine whether the DSC **144** will submit a bid for the available resources, determine the resources for which the DSC **144** will submit bids, and/or perform other similar operations.

[0185] With reference to FIG. **10**B, in operation **1012**, the DPC **146** may reject the AVAILABLE BIDS REQUEST message received from lessee DSC **144** by generating and sending a AVAILABLE BIDS REJECT message to the DSC **144**. The DPC **146** may be configured to reject the AVAILABLE BIDS REQUEST message in response to determining (e.g., as part of operation **1004** or **1006**) that one or more of the PLMN IDs supplied in the request message is not from any of the known networks, that one or more of the Grid IDs supplied in the request message is not valid with respect to the supplied PLMN ID, and/or that there are no resources/bids available in the relevant grids.

[0186] In an embodiment, the DPC **146** may be configured to generate the AVAILABLE BIDS REJECT message to include a message type information element (IE), a message ID IE, a cause IE, a criticality diagnostics IE, and a sequence number IE. The cause IE may include a reason code (e.g., Invalid PLMN ID, Invalid Grid ID, etc.) for the rejection of the available bids request, which may be determined in operation block **1005**. The sequence number IE may include the same sequence number value that was included in the AVAILABLE BIDS REQUEST message received from lessee DSC **144**. As such, the DPC **146** and/or DSC **144** may be configured to use sequence number IEs in the request and response messages to correlate those messages.

[0187] In operation block **1014**, the DSC **144** may use the information included in the received AVAILABLE BIDS

REJECT message to perform various failure-response operations. For example, the DSC **144** may determine whether to send another AVAILABLE BIDS REQUEST message to the DPC **146**, determine whether to send another AVAILABLE BIDS REQUEST message to a different DPC, etc.

[0188] FIGS. **11**A and **11**B illustrate a DSAAP bidding method **1100** of bidding for DSC resources, which allows different lessee networks to bid for resources that are available from lessor networks. In the examples illustrated in FIGS. **11**A and **11**B, the DSAAP method **1100** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component.

[0189] In an embodiment, the DSC **144** and/or DPC **146** may be configured to perform DSAAP method **1100** after the DSC **144** retrieves the list of resources that are available for bidding (e.g., after performing DSAAP method **1000**). In various embodiments, the DSC **144** and/or DPC **146** may be configured to perform DSAAP method **1100** continuously or repeatedly until the expiration of a bidding time. In an embodiment, the DPC **146** may be configured to select a winning bid (i.e., bid highest bid value) at the expiry of a bidding time.

[0190] In operation **1102** of method **1100** illustrated in FIGS. **11**A and **11**B, the lessee DSC **144** may generate and send a DSC BID REQUEST message to the DPC **146** to bid for one or more of the resource that are determined to be available from a lessor network, (i.e., one or more of resources included the list of resources obtained via the performance of method **1000**). The lessee DSC **144** may be configured to generate the DSC BID REQUEST message to include any or all of a message type information element (IE), a message ID IE, a DSC identity IE, a DSC type IE, bid ID IE, a PLMN ID IE, and a bid amount IE. The bid ID IE may include information suitable for identifying a specific resource for which the lessee DSC **144** places a bid. The PLMN ID IE may include information suitable for use in identifying the PLMN ID of the network associated with the resources identified in the bid ID IE. The bid amount IE may include a monetary amount in a currency (e.g., USD), or the bid value.

[0191] In an embodiment, the lessee DSC **144** may be configured to generate the DSC BID REQUEST message to include a bid amount IE value that is greater than a minimum bid amount specified in a bid listing for the specific resource/bid ID. In an embodiment, the lessee DSC **144** may be configured to obtain the minimum bid amount and/or bid listing from the received AVAILABLE BIDS RESPONSE message (e.g., the message sent as part of operation **1008** illustrated in FIG. **10**A).

[0192] In operation block **1104** illustrated in FIG. **11**A, the DPC **146** may use the information included in the received DSC BID REQUEST message to determine whether the bid (resource bid) is valid and is to be accepted, such as by determining whether the bid complies with the policies and rules of the DSA system and the requirements of the lessor network. In operation **1106**, the DPC **146** may generate and send DSC BID ACCEPT message to the DSC in response to determining that the bid is valid and/or is to be accepted. The DPC **146** may be configured to generate the DSC BID ACCEPT message to include any or all of a message type information element (IE), a message ID IE, a bid ID IE, and other information suitable for informing the DSC **144** that the bid has been determined to be valid and/or has been accepted.

[0193] It should be noted that, in the example discussed above, the DSC BID ACCEPT message informs the DSC **144** that the bid is valid/accepted, not that lessee DSC **144** has won the bid. The winning lessee DSC may be informed via DSC BID WON message when the DPC **146** determines that the bid time has expired and that lessee DSC is the highest bidder at the time of bid expiry. Similarly, the DPC **146** may inform lessee DSC(s) who participated in the bidding process but submitted losing bids that they did not submit a winning bid via a DSC BID LOST message. The DSC BID WON message and DSC BID LOST message are discussed in more detail further below.

[0194] With reference to FIG. **11**B, in operation block **1108**, the DPC **146** may use the information included in the received DSC BID REQUEST message to determine that the bid is not valid and is not to be accepted. For example, the DPC **146** may use the received information to determine that the bid does not comply with the policies/rules of the DSA system and/or does not comply with the requirements of the lessor network (e.g., does not meet the minimum asking price, etc.). As further examples, the DPC **146** may be configured to determine that the bid is not valid or is not to be accepted in response to determining that the bid amount specific in bid amount IE in the BID REQUEST message is not higher than the minimum bid, that the bid amount is not the highest among currently offered bids, that the bid id included in the bid ID IE is invalid, or that the bid/resource is no longer available for bidding (e.g., due to expiry, end of auction, bid withdrawn or invalid bid id).

[0195] In operation **1110**, the DPC **146** may generate and send a DSC BID REJECT message to the DSC **144**. The DPC **146** may be configured to generate the DSC BID REJECT message to include any or all of a message type information element (IE), a message ID IE, a bid ID IE, a cause IE, and a criticality diagnostics IE. The bid ID IE in the DSC BID REJECT message may include the same value as the bid identifier included in the received DSC BID REQUEST message. The cause IE may include a reason code identifying a reason for the rejection of the bid (e.g., minimum bid not met, outbid, bid not found, etc.). In operation block **1112**, the DSC **144** may use information included in the received DSC BID REJECT message to perform various bid request failure-response operations, such as operations to determine whether to rebid for the resources, to generate a new DSC BID REQUEST message that includes a valid bid ID, etc.

[0196] FIGS. **12**A through **12**D illustrate a DSAAP notification method **1200** of informing participating networks of the results of the bidding operations. That is, DSAAP notification method **1200** may be performed to inform DSCs **144** of a result of an auction (e.g., that they submitted a winning bid, that they have been outbid, that they submitted a losing bid, that the auction was cancelled, etc.). In the examples illustrated in FIGS. **12**A-**12**D, the DSAAP notification method **1200** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component.

[0197] DSAAP notification method **1200** may be performed after the DPC **146** notifies the DSC **144** that the bid has been accepted (e.g., after operation **1106** illustrated in FIG. **11**). The DSAAP notification method **1200** also may be performed after the expiry of a bidding time and/or in response to the DPC **146** detecting an event or condition (e.g., new bid received, outbid, etc.).

[0198] In operation block **1202** illustrated in FIG. **12**A, the DPC **146** may determine that the bid amount specific in bid amount IE in the last, latest, or most current BID REQUEST message accepted from the DSC **144** is not the highest among the current bids. In operation **1204**, the DPC **146** may generate and send a DSC BID OUTBID message to the DSC **144** to inform the lessee DSC **144** that its earlier bid was outbid by a higher bid from another lessee DSC and/or that their earlier bid is no longer valid. In various embodiments, the DPC **146** may generate the DSC BID OUTBID message to include any or all of a message type information element (IE), a message ID IE, a cause IE, a bid info IE, a criticality diagnostics IE, a DSC ID IE and a BID ID IE.

[0199] The DSC ID IE may include information that is suitable for use in identifying the specific lessee DSC **144**. The BID ID IE may include a bid ID suitable for use in identifying the submitted bid that has been outbid. In operation block **1206**, the lessee DSC **144** may perform various bid-outbid failure-response operations, such as by determining whether to submit a higher bid for the resources to that DPC **146**, to submit a bid to a different DPC **146**, to drop existing calls to free bandwidth, etc.

[0200] With reference to FIG. **12**B, in operation block **1210**, the DPC **146** may determine that the bidding time has expired and that the bid amount specific in bid amount IE in the last, latest, or most current BID REQUEST message accepted from the DSC **144** is the highest among the current bids. In operation **1212**, the DPC **146** may generate and send a DSC BID WON message to the DSC **144** to inform the lessee DSC **144** that their earlier bid is the winning bid. In various embodiments, the DPC **146** may generate the DSC BID WON message to include any or all of a message type information element (IE), a message ID IE, a bid ID IE, a bid info IE, a DSC ID IE, and original bid details such as bandwidth, MBPS, duration and the winning bid amount, etc. The DSC ID IE may include information that is suitable for use in identifying the specific lessee DSC **144**. The bid ID IE may include a bid identifier suitable for identifying the bid that won the resource auction/bidding operations.

[0201] In operation block **1214**, the winning lessee DSC **144** may wait to receive DSC RESOURCES ALLOCATED message from the DPC **146** before scheduling its network equipment and device (e.g., wireless devices) to start using the resources and/or for the resources to be made available for use (i.e. scheduling for the time of day when the resources will be ready for use by the winning lessee network). In operation block **1216**, the DPC **146** may close the auction, such as by rejecting further bids from other networks for the resources won by the bid submitted by lessee DSC **144**.

[0202] With reference to FIG. **12**C, in operation block **1220**, the DPC **146** may determine that the bidding time has expired and that the bid amount specific in bid amount IE in the last, latest, or most current BID REQUEST message accepted from the DSC **144** is not the highest among the current bids. In operation **1222**, the DPC **146** may generate and send a DSC BID LOST message to the DSC **144** to inform the lessee DSC **144** that its earlier bid has not won the bid and the auction/bid is closed due to another lessee DSC winning the auction. In various embodiments, the DPC **146** may generate the DSC BID LOST message to include any or all of a message type information element (IE), a message ID IE, a bid ID IE, and a DSC ID IE. The DSC ID IE may include information that is suitable for use in identifying the specific lessee DSC **144** that submitted the losing bid and/or to which the DSC BID LOST message is sent. The bid ID IE may include a bid identifier suitable for use in identifying the submitted bid.

[0203] In operation block **1224**, the lessee DSC **144** may perform various failure response operations, such as determining whether to submit a bid to for other available resources, whether to drop existing calls to free up resources, etc. In operation block **1226**, the DPC **146** may close the auction and/or allow the losing lessee DSCs to bid for other available resources.

[0204] With reference to FIG. **12**D, in operation block **1230**, the DPC **146** may determine that the auction for a network resource that the DSC **144** previously submitted a bid has been cancelled. For example, the DPC **146** may determine that the auction has been withdrawn by lessor network operator or that the auction has been cancelled by DPC operator for administrative reasons. In operation **1232**, the DPC **146** may generate and send a DSC BID CANCELLED message to the DSC **144** to inform the lessee DSC **144** that the auction has been cancelled. In various embodiments, the DPC **146** may generate the DSC BID CANCELLED message to include any or all of a message type information element (IE), a message ID IE, a bid ID IE, a DSC ID IE, and a cause IE. The DSC ID IE may include information that is suitable for use in identifying the specific lessee DSC **144**. The bid ID IE may include a bid identifier suitable for use in identifying the resource/bid for which the auction has been cancelled. The cause IE may include a reason code for the bid's cancellation (e.g., auction withdrawn, auction cancelled, etc.). In operation block **1234**, the lessee DSC **144** may perform various failure-response operations, such as by determining whether to submit a bid to a different DPC **146**, to drop calls, etc.

[0205] FIGS. **13**A and **13**B illustrate a DSAAP purchase method **1300** of allowing a lessee network to make an immediate (or near immediate) purchase and/or claim of use for a resource that is made available for allocation by a lessor network. In the examples illustrated in FIGS. **13**A and **13**B, the DSAAP purchasing method **1300** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component. In an embodiment, the DSC **144** and DPC **146** may be configured to perform DSAAP method **1300** after the DSC **144** retrieves/receives a list of resources that are available for purchase (e.g., after performing DSAAP method **1000** discussed above with reference to FIG. **10**).

[0206] In operation block **1302** illustrated in FIGS. **13**A and **13**B, the lessee DSC **144** may identify and select a specific resource for immediate purchase from the list of resources (e.g., list of resources obtained from performing DSAAP method **1000** discussed above). In various the embodiments, the lessee DSC **144** may select a resource that is scheduled for bidding, that is currently being auctioned, that is only made available for immediate purchase, etc. In operation **1304**, the DSC **144** may generate and send DSC BUY REQUEST message to the DPC **146** to request to buy the identified/selected resources from a lessor network.

[0207] In various embodiments, the DSC **144** may generate the DSC BUY REQUEST message to include any or all of a message type information element (IE), a message ID IE, a DSC identity IE, a DSC type IE, a bid ID IE, a buy amount IE, and a PLMN ID IE. The PLMN ID IE may include information suitable for use in identifying the PLMN ID of the network associated with the bid, which may identified via the bid

ID IE. The buy amount IE may include the amount (e.g., in USD) of the bid (i.e., bid value) submitted by the lessee DSC **144**.

[0208] In an embodiment, the DSC **144** may be configured to generate the DSC BUY REQUEST message to include a buy amount value that is equal to an amount identified via a buy amount IE in a listing for the bid ID included in a received AVAILABLE BIDS RESPONSE message (which is discussed above with reference to FIG. **10**).

[0209] In operation block **1306** illustrated in FIG. **13**A, the DPC **146** may use the information included in the received DSC BUY REQUEST message to identify the requested resource, the network associated with the request resource, whether the requested resource is currently being auctioned, whether the requested resource has been made available for immediate purchase, a minimum purchase amount requested for the immediate purchase of that resource, and/or whether the buy amount included in the received DSC BUY REQUEST message is equal to (or greater than) the requested purchase amount. In the example illustrated in FIG. **13**A, as part of operation block **1306**, the DPC **146** determines that the buy amount included in the received DSC BUY REQUEST message is greater than or equal to the requested purchase amount.

[0210] In operation **1308**, the DPC **146** may generate and send a DSC BUY ACCEPT message to the DSC **144** to inform the lessee DSC **144** that it has successfully purchased/leased the resource for use. In various embodiments, the DPC **146** may generate the DSC BUY ACCEPT message to include any or all of a message type information element (IE), a message ID IE, and a bid ID IE. In operation block **1310**, the DPC **146** may terminate, stop, or close an active auction for that resource and/or perform similar operations so that the resource is no longer available for bidding or buying by other lessee DSCs.

[0211] With reference to FIG. **13**B, in operation block **1312**, the DPC **146** may use the information included in the received DSC BUY REQUEST message (e.g., as part of operation **1304**) to determine that the bid (buy request) is to be rejected. For example, the DPC **146** may determine that the buy amount specific in buy amount IE in the received DSC BUY REQUEST message is less than the requested purchase amount. As another example, the DPC **146** may determine that the bid ID value included in the bid ID IE is invalid, or that the resource/bid is no longer available for bidding (due to expiry, end of auction, bid withdrawn, invalid bid ID, etc.).

[0212] In operation **1314**, the DPC **146** may generate and send a DSC BUY REJECT message to the DSC **144**. In various embodiments, the DPC **146** may generate the DSC BUY REJECT message to include any or all of a message type information element (IE), a message ID IE, a bid ID IE and a cause IE. The value of the bid ID IE may be the same as the bid identifier included in the DSC BUY REQUEST message received as part of operation **1304**. The cause IE may include a reason code for the rejection of the buy request (e.g., requested purchase price not met, bid not found, etc.). In operation block **1316**, the DSC **1316** may perform various failure-response operations, such as determining whether to submit a new purchase request with a higher bid amount. In operation block **1318**, the DPC **146** perform various operations so to make that resource available for bidding or buying by other lessee DSCs.

[0213] FIGS. **14**A and **14**B illustrate a DSAAP resource allocation method **1400** of allocating resources in a lessor network for access and use by components in a lessee network. In the examples illustrated in FIGS. **14**A and **14**B, the DSAAP resource allocation method **1400** is performed by processing cores in a DPC **146** component, a lessee DSC **144***a* component, and a lessor DSC **144***b* component, each of which may include all or portions of a DSAAP module/component.

[0214] In operation block **1402** illustrated in FIGS. **14**A and **14**B, the DPC **146** may determine that the lessee DSC **144***a* has successfully purchased or won an auction for a resource in a lessor network represented by the lessor DSC **144***b*. In operation **1404** illustrated in FIG. **14**A, the DPC **146** may generate and send a DSC BID SUCCESS message to the lessor DSC **144***b* to inform the lessor network that one or more of its allocated resources/bids has been won by the lessee DSC **144***a*.

[0215] In various embodiments, the DPC **146** may generate the DSC BID SUCCESS message to include any or all of a message type information element (IE), a message ID IE, a cause IE, and a criticality diagnostics IE. In a further embodiment, the DPC **146** may be configured to generate the DSC BID SUCCESS message to also include any or all of a bid ID IE, a DSC ID IE, and a bid value IE. These additional information elements may be used to communicate information regarding the winning bid. For example, the bid ID IE may include a bid ID that corresponds to the bid that successfully participated in and won the auction for the resources. The DSC ID IE may include the DSC ID of the auction winner (i.e., the lessee DSC **144***a*). The bid value IE may include the winning bid amount and/or the purchase price of the resources.

[0216] In operation **1404**, the lessor DSC **144***b* may generate and send DSC RESOURCES ALLOCATED message to the DPC **146** to allocate/commit the resources for access and use by components in the lessee network. The lessor DSC **144***b* may be configured to generate DSC RESOURCES ALLOCATED message to include any or all of a message type information element (IE), a message ID IE, a bid iD, a PLMN-ID Grid ID Cell ID list IE, a PLMN ID IE, a grid ID IE, list of cell IDs IE, and various auction/resource details (e.g., bandwidth, MBPS, duration, etc.). In an embodiment, the PLMN ID IE, a grid ID IE, and list of cell IDs IE may be included in the PLMN-ID Grid ID Cell ID list IE. The PLMN ID IE may include the PLMN ID of the lessor network allocating the resources, which may be the same PLMN ID/network identified in the winning bid. The grid ID IE and list of cell IDs IE may include information suitable for identifying the grid/cells associated with the resources. These values may be the same as the grid/cell values included in the winning bid.

[0217] In operation **1406**, the DPC **146** may forward the received DSC RESOURCES ALLOCATED message to the winning lessee DSC **144***a* to enable the lessee DSC **144***a* to start using the allocated resources of lessor network resources. In operation block **1408**, the lessee DSC **144***a* may schedule its network equipment to start using lessor network resources from the time of day specified as part of the bid and/or included in the received DSC RESOURCES ALLOCATED message.

[0218] With reference to FIG. **14**B, in operation block **1410**, the lessor DSC **144***b* may determine that the resources submitted for auction should be withdrawn and/or to forego allocating the submitted resources to a winner of the auction. The lessor DSC **144***b* may determine to withdraw the

resources after the DPC **146** determines that lessee network purchased or won an auction for those resources and/or for any of a variety of reasons (e.g., unforeseen or administrative reasons, etc.).

[0219] In operation **1412**, the lessor DSC **144***b* may generate and send a DSC RESOURCES WITHDRAWN message to the DPC **146** to withdraw the resources. The lessor DSC **144***b* may generate the DSC RESOURCES WITHDRAWN message to include any or all of a message type information element (IE), a message ID IE, a bid ID IE, a cause IE, and a PLMN-ID Grid ID Cell ID list IE. The bid ID IE may include information that is suitable for use in identifying the bid. The cause IE may include a reason code that describes the reason for withdrawal of resource allocations (e.g., resources not available, resources withdrawn, administrative, etc.).

[0220] In operation **1414**, the DPC **146** may forward the received DSC RESOURCES WITHDRAWN message to the lessee DSC **144***a*, which may have submitted a winning bid for the withdrawn resources. In operation block **1416**, the lessee DSC **144***a* may perform various failure-response operations, such as determining whether to participate in another auction, whether to bid on a different resource, determining whether to drop calls to free up resources, etc.

[0221] FIGS. **15**A and **15**B illustrate an embodiment DSAAP backoff method **1500** of selectively handing over a wireless device from a lessor network back to the lessee's network to which the wireless device subscribes (i.e. its home PLMN). In the examples illustrated in FIGS. **15**A and **15**B, the DSAAP backoff method **1500** is performed by processing cores in a DPC **146** component, a lessee DSC **144***a* component, and a lessor DSC **144***b* component, each of which may include all or portions of a DSAAP module/component.

[0222] In operation block **1502** illustrated in FIGS. **15**A and **15**B, the lessor DSC **144***b* may determine that its network resources from the cells that are part of a prior auction are in congestion. That is, the lessor DSC **144***b* may determine that it requires access or use of its allocated resources. In operation **1504**, the lessor DSC **144***b* may generate and send a DSC BACKOFF COMMAND message to the DPC **146** to selectively handover wireless device(s) that are using the allocated resources of the lessor network back to the lessee network (i.e. its home PLMN).

[0223] The lessor DSC **144***b* may be configured to generate the DSC BACKOFF COMMAND message to include any or all of a message type information element (IE), a message ID IE, a bid ID IE, a UE identity IE, a measurement report IE, handoff cell information IE, a cause IE, and a DSC backoff response timer IE.

[0224] The UE identity IE may include information suitable for use in determining identity related information for the wireless device (or UE), such as the international mobile subscriber identity (IMSI) of the wireless device or its network.

[0225] The measurement report IE may include the latest, last, or most recent measurement report E-UTRAN RRC message received by the lessor network for the identified wireless device (i.e., the wireless devices that are requested to backoff to lessee network).

[0226] The bid ID IE may include a bid ID value corresponding to the bid that successfully participated in and completed/won the auction. The bid ID may be used to identify the auction/contract associated with the backoff operations (i.e., the auction/contract for which the resources were allocated).

[0227] In an embodiment, the lessor DSC **144***b* may be configured to determine whether there are multiple bid IDs that correspond to a congested cell. In an embodiment, the lessor DSC **144***b* may be configured to select the bid ID value from a plurality of bid IDs in response to determining that there are multiple bid IDs that correspond to a congested cell. In various embodiments, the lessor DSC **144***b* may be configured to select the bid ID value based on an operator policy provisioned at the lessor DSC **144***b*, based on a previous agreement, based on a policy/rule previously negotiated by lessor and lessee network operators, etc.

[0228] In operation **1506**, the DPC **146** may forward the received DSC BACKOFF COMMAND message to the lessee DSC **144***a*. In operation block **1508**, the lessee DSC **144***a* may use the information in the UE identity IE of the received DSC BACKOFF COMMAND message identify wireless device(s) that are to be subjected to the backoff operations (i.e., the wireless devices that are to be handed back).

[0229] In operation block **1510**, the lessee DSC **144***a* may use the information included in the measurement report IE of the received DSC BACKOFF COMMAND message to determine, identify, and/or select a target cell (within lessee network) to which the identified wireless device(s) are to be handed over (the lessor network may have previously enabled measurement reporting from the wireless devices, such as when they attached, or were handed over, to the lessor network.)

[0230] In operation **1512**, the lessee DSC **144***a* may generate and send a DSC BACKOFF RESPONSE message to the DPC **146**. The lessee DSC **144***a* may be configured to generate the DSC BACKOFF RESPONSE message to include any or all of a message type information element (IE), a message ID IE, a bid ID IE, a UE identity IE, a handoff cell information IE, and a cause IE. In an embodiment, the lessee DSC **144***a* may be configured to generate the DSC BACKOFF RESPONSE message to include the cause IE (or a value for the cause IE) in response to determining that a suitable target cell (within lessee network) could not be identified or selected for the handed over. The value of the cause IE may identify a cause of the failure, such as network overload, no appropriate target cell found, or unknown wireless device/UE. In an embodiment, the lessee DSC **144***a* may be configured to generate the DSC BACKOFF RESPONSE message to include a value (e.g., target cell information) for the handoff cell information IE in response to successfully identifying a target cell (within lessee network) to which the wireless device may be handed over.

[0231] In operation **1514**, the DPC **146** may identify the lessor DSC **144***a* based on the bid id IE included in the received DSC BACKOFF RESPONSE message, and forward the received DSC BACKOFF RESPONSE message to the lessor DSC **144***b*. In operation block **1516**, the lessor DSC **144***b* may determine whether the received DSC BACKOFF RESPONSE message includes a handoff cell information IE (or a valid value for the handoff cell information IE). In response to determining that the received DSC BACKOFF RESPONSE message includes a handoff cell information IE (or a valid value for the handoff cell information IE), in operation block **1518**, the lessor DSC **144***b* may use the target cell information included in the handoff cell information IE to encode a HANDOVER REQUIRED message. In operation block **1520**, the lessor DSC **144***b* may and initiate **51** based handover procedure to handover the wireless device from lessor network to lessee network.

[0232] With reference to FIG. **15**B, in operation block **1552**, the lessor DSC **144***b* may determine that the DPC **146** has not responded to the DSC BACKOFF COMMAND message (sent as part of operation **1504**) within a time period identified in the DSC backoff response timer IE included in the DSC BACKOFF COMMAND message. Alternatively or additionally, in operation block **1554**, the lessor DSC **144***b* may determine that there is significant or severe network congestion or administrative reasons that require withdraw of the allocation of all remaining network resources pertaining to the resources/bid id included or identified in the DSC BACKOFF COMMAND message.

[0233] In operation **1556**, the lessor DSC **144***b* may generate and send a DSC RESOURCES WITHDRAWN message to the DPC **146**. In operation **1558**, the DPC **146** may forward the received DSC RESOURCES WITHDRAWN message to the lessee DSC **144***a* to withdraw the allocation of the remaining network resources. In operation block **1560**, the lessee DSC **144***a* may perform various resource withdrawn failure-response operations, such as dropping calls, determining whether to bid for new resources, etc.

[0234] FIG. **16**A illustrates an embodiment DSC initiated DSAAP de-registration method **1600** for terminating operations. In the example illustrated in FIG. **16**A, the DSC initiated DSAAP de-registration method **1600** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component.

[0235] In operation block **1602**, the DSC **144** may determine that it needs to terminate DSA operations. In operation **1604**, the DSC **144** may generate and send a DSC DE-REGISTER message to the DPC **146**. The DSC **144** may be configured to generate the DSC DE-REGISTER message to include any or all of a message type information element (IE), a message ID IE, a backoff timer IE, and a cause IE that identifies a cause for the termination of operations. In operation block **1606**, the DPC **146** may clear all the related resources associated with the DSC **144** and/or perform other similar operations to de-register the DSC **144** in response to receiving the DSC DE-REGISTER message.

[0236] FIG. **16**B illustrates an embodiment DPC initiated DSAAP de-registration method **1650** for terminating operations. In the example illustrated in FIG. **16**B, the DPC initiated DSAAP de-registration method **1650** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component.

[0237] In operation block **1652**, the DPC **146** may determine that it needs to terminate DSA operations with the DSC **144**. In operation **1654**, the DPC **146** may generate and send a DSC DE-REGISTER message to the DSC **144**. The DPC **146** may be configured to generate the DSC DE-REGISTER message to include any or all of a message type information element (IE), a message ID IE, a backoff timer IE, and a cause IE that identifies a cause for the termination of operations (e.g., overload, unspecified, etc.). In operation block **1656**, the DPC **146** may clear all the related resources associated with the DSC **144** and/or perform other similar operations to de-register the DSC **144**.

[0238] In operation block **1658**, the DSC **144** may perform various de-registration failure response operations based on the information included in the received DSC DE-REGISTER message. For example, the DSC **144** may be configured to not retry registration to the same DPC **146** for at least the duration indicated in the backoff timer IE included in the received DSC DE-REGISTER message when the value of the cause IE in the DSC DE-REGISTER message is set to "overload."

[0239] FIG. **17**A illustrates a DSC initiated DSAAP error indication method **1700** for reporting errors in accordance with an embodiment. In the example illustrated in FIG. **17**A, method **1700** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component.

[0240] In operation block **1702**, the DSC **144** may detect an error or error condition (e.g., a protocol error, etc.). In operation **1704**, the DSC **144** may generate and send an ERROR INDICATION message to the DPC **146**. The DSC **144** may be configured to generate the ERROR INDICATION message to include any or all of a message type information element (IE), a message ID IE, cause IE, and a criticality diagnostics IE. The cause IE may include information suitable for use in identifying a cause or type of the error (e.g., transfer syntax error, abstract syntax error, logical error, etc.). The criticality diagnostics IE may include a procedure code IE, a triggering message IE, and a procedure criticality IE. In operation block **1706**, the DSC **144** and/or DPC **146** may perform various error-response operations based on the detected error or information included in the received ERROR INDICATION message. The error detection and response operations are discussed in detail further below.

[0241] FIG. **17**B illustrates an embodiment DPC initiated DSAAP error indication method **1750** for reporting errors in accordance with another embodiment. In the example illustrated in FIG. **17**B, method **1750** is performed by processing cores in a DPC **146** component and a DSC **144** component, each of which may include all or portions of a DSAAP module/component.

[0242] In operation block **1752**, the DPC **146** may detect an error condition. In operation **1754**, the DPC **146** may generate and send an ERROR INDICATION message to the DSC **144**. The DPC **146** may be configured to generate the ERROR INDICATION message to include a cause information element (IE) that identifies a cause for the error. In operation block **1756**, the DSC **144** and/or DPC **146** may perform various error-response operations based on the information included in the received ERROR INDICATION message.

[0243] As mentioned above, the DSC **144** and DPC **146** may be configured perform various error-response or failure response operations in response to detecting an error or failure condition. As part of these operations, the DSC **144** and/or DPC **146** may identify the type or cause of the error/failure condition, and tailor their responses based on the identified type or cause. For example, the DSC **144** and/or DPC **146** may be configured to determine whether a detected error is a protocol error, and tailor their responses accordingly.

[0244] Protocol errors include transfer syntax errors, abstract syntax errors, and logical errors. A transfer syntax error may occur when the receiving functional DSAAP entity (e.g., DSC, DPC, etc.) is not able to decode the received physical message. For example, transfer syntax errors may be detected while decoding ASN.1 information in a received message. In an embodiment, the DSC **144** and DPC **146** components may be configured to retransmit or re-request a DSAAP message in response to determining that a detected error is a transfer syntax error (e.g., as part of the error-response operations).

[0245] An abstract syntax error may occur when the receiving functional DSAAP entity (e.g., DSC, DPC, etc.) receives information elements (IEs) or IE groups that cannot be comprehended or understood (i.e., an unknown IE id). An abstract syntax error may also occur when the entity receives an information element (IE) for which a logical range (e.g., allowed number of copies) is violated. The DSC **144** and DPC **146** components may be configured to detect or identify these types of abstract syntax errors (i.e., cannot comprehend abstract syntax error), and in response, perform error-response operations based on criticality information included in the corresponding DSAAP message. Additional details regarding these operations and the criticality information are provided further below.

[0246] An abstract syntax error may also occur when the receiving functional DSAAP entity does not receive IEs or IE groups, but according to the specified presence of the object, the IEs or IE groups should have been present in the received message. The DSC **144** and DPC **146** components may be configured to detect or identify these particular types of abstract syntax errors (i.e., missing IE or IE group), and in response, perform error-response operations based on criticality information and presence information for the missing IE/IE group. Additional details regarding these operations, criticality information, and presence information are provided further below.

[0247] An abstract syntax error may also occur when the receiving entity receives IEs or IE groups that are defined to be part of that message in wrong order or with too many occurrences of the same IE or IE group. In addition, an abstract syntax error may also occur when the receiving entity receives IEs or IE groups, but according to the conditional presence of the concerning object and the specified condition, the IEs or IE groups should not have been present in the received message. The DSC **144** and DPC **146** components may be configured to detect or identify such abstract syntax errors (i.e., wrong order, too many occurrences, erroneously present, etc.), and in response, reject or terminate a procedure or method associated with the error (e.g., the method that caused the error). The DSC **144** and DPC **146** components may reject or terminate the procedure/method as part of the error-response operations.

[0248] In the various embodiments, the DSC **144** and DPC **146** components may be configured to continue to decode, read, or process a DSAAP message after detecting, identifying, or determining that an abstract syntax error occurred for that message. For example, the DSC **144** and DPC **146** components may skip a portion of the message that includes an error, and continue processing the other portions of the message. As part of this continued processing, the DSC **144** and DPC **146** components may detect or identify additional abstract syntax errors.

[0249] In an embodiment, the DSC **144** and DPC **146** components may be configured to perform error-response operations for each detected abstract syntax error and/or based on the criticality information and presence information for the IE/IE group associated with the abstract syntax error.

[0250] As mentioned above, each DSAAP message may include, or may be associated with, criticality information, presence information, range information, and assigned criticality information. In the various embodiments, a receiving functional DSAAP entity (e.g., DSC, DPC, etc.) may be configured to use any or all of such information (e.g., criticality information, presence information, etc.) when detecting an error, identifying the type of the error, or the specific error-response that are to be performed. That is, the entity may perform different operations depending on the values of the criticality information, presence information, range information, and/or assigned criticality information.

[0251] In an embodiment, the receiving functional DSAAP entity (e.g., DSC, DPC, etc.) may be configured to use the presence information included in a DSAAP message when identifying the type of error and the specific error-response operations that are to be performed for the identified error type. For example, the entity may use the presence information to determine whether the presence of an information element (IE) is optional, conditional, or mandatory (e.g., with respect to RNS application) for that message or communication. The entity may determine that an abstract syntax error has occurred when a received message is missing one or more information elements that are determined to be mandatory (or conditional when the condition is true).

[0252] In an embodiment, the receiving functional DSAAP entity (e.g., DSC, DPC, etc.) may be configured use the criticality information when identifying the specific error-response operations that are to be performed. That is, each DSAAP message may include criticality information for each individual information element (IE) or IE group included in that message. The values of criticality information for each IE or IE group may include "Reject IE," "Ignore IE and Notify Sender," and "Ignore IE." The receiving entity (e.g., DSC, DPC, etc.) may use this criticality information to determine that an IE, an IE group, or an EP is incomprehensible, identify the condition as an abstract syntax error (i.e., a cannot comprehend abstract syntax error), and/or to identify the error-response operations that are to be performed (e.g., reject, ignore, notify, etc.).

[0253] In an embodiment, the receiving entity (e.g., DSC, DPC, etc.) may be configured to reject a method/procedure and initiate a DSAAP error indication method (discussed above with reference to FIGS. **17**A-B) in response to determining that an information element (IE) included in a message received during the performance of that method/procedure is incomprehensible, and that value of the criticality information for that IE is set to "Reject IE."

[0254] For example, when a message that initiates a method/procedure (e.g., a DSC REGISTER REQUEST message, etc.) is received, determined to include one or more IEs/IE groups that are incomprehensible and marked as "Reject IE," the receiving entity may the reject the method/procedure by not executing any of the functional requests included in that message. The receiving entity may also report the rejection of one or more IEs/IE groups using the message normally used to report unsuccessful outcome of the procedure. When the information in the received initiating message is insufficient and cannot be used to determine a value for all IEs that are required to be present in the message used to report the unsuccessful outcome of the procedure, the receiving entity may terminate the procedure and initiate a DSAAP error indication method/procedure.

[0255] As a further example, when a message initiating a method/procedure that does not have a message to report unsuccessful outcome is received, and that message includes one or more IEs/IE groups marked with "Reject IE" which the receiving entity does not comprehend, the receiving entity may terminate the method/procedure and initiate a DSAAP error indication method/procedure.

[0256] As yet another example, when a response message (e.g., a DSC REGISTER RESPONSE message, etc.) is received that includes one or more IEs marked with "Reject IE" which the receiving entity does not comprehend, the receiving entity may consider the method/procedure as being unsuccessfully terminated, and initiate a local error handling method.

[0257] In an embodiment, the receiving entity (e.g., DSC, DPC, etc.) may be configured to ignore or skip a method/procedure and initiate an DSAAP error indication method (discussed above with reference to FIGS. **17**A-B) in response to determining that an information element (IE) included in a message received during the performance of that method/procedure is incomprehensible, and that value of the criticality information for that IE is set to "Ignore IE and Notify Sender."

[0258] As an example, when a message initiating a method/procedure is received containing one or more IEs/IE groups marked with "Ignore IE and Notify Sender" which the receiving entity does not comprehend, the receiving entity may ignore the content of the incomprehensible IEs/IE groups, continue with the method/procedure as if the incomprehensible IEs/IE groups were not received (except for the reporting) using the comprehended IEs/IE groups, and report in the response message of the method/procedure that one or more IEs/IE groups have been ignored. When the information received in the initiating message is insufficient to determine a value for all IEs that are required to be present in the response message, the receiving entity may terminate the method/procedure and initiate a DSAAP error indication method/procedure.

[0259] As a further example, when a message initiating a method/procedure that does not have a message to report the outcome of the method/procedure is received containing one or more IEs/IE groups marked with "Ignore IE and Notify Sender" which the receiving entity does not comprehend, the receiving entity may ignore the content of the not comprehended IEs/IE groups, continue with the method/procedure as if the not comprehended IEs/IE groups were not received (except for the reporting) using the understood IEs/IE groups, and initiate a DSAAP error indication method/procedure to report that one or more IEs/IE groups have been ignored.

[0260] As yet another example, when a response message is received containing one or more IEs/IE groups marked with "Ignore IE and Notify Sender" which the receiving entity does not comprehend, the receiving entity may ignore the content of the not comprehended IE/IE groups, continue with the method/procedure as if the not comprehended IEs/IE groups were not received (except for the reporting) using the understood IEs/IE groups and initiate a DSAAP error indication method/procedure.

[0261] In an embodiment, the receiving entity (e.g., DSC, DPC, etc.) may be configured to ignore or skip a method/procedure in response to determining that an information element (IE) included in a message received during the performance of that method/procedure is incomprehensible, and that value of the criticality information for that IE is set to "Ignore IE."

[0262] As an example, when a message initiating a method/procedure is received containing one or more IEs/IE groups marked with "Ignore IE" which the receiving entity does not comprehend, the receiving entity may ignore the content of the not comprehended IEs/IE groups and continue with the method/procedure as if the not comprehended IEs/IE groups were not received using only the understood IEs/IE groups.

[0263] As a further example, when a response message is received that includes one or more IEs/IE groups marked with "Ignore IE" which the receiving entity does not comprehend, the receiving entity may ignore the content of the not comprehended IEs/IE groups and continue with the method/procedure as if the not comprehended IEs/IE groups were not received using the understood IEs/IE groups.

[0264] When reporting not comprehended IEs/IE groups marked with "Reject IE" or "Ignore IE and Notify Sender" using a response message defined for the method/procedure, the Information Element Criticality Diagnostics IE may be included in the Criticality Diagnostics IE for each reported IE/IE group.

[0265] In an embodiment, the receiving entity (e.g., DSC, DPC, etc.) may be configured to initiate a DSAAP error indication method (discussed above with reference to FIGS. **17**A-B) in response to determining that it cannot decode a type of message IE in a received message. In an embodiment, the entity may be configured to only consider the IEs specified in the specification version used by the component when determining the correct order for the IE included in a message.

[0266] In an embodiment, the receiving entity (e.g., DSC, DPC, etc.) may be configured to treat the missing IE/IE group according to the criticality information for the missing IE/IE group in the received message specified in the version of the present document used by the receiver.

[0267] As an example, the receiving entity (e.g., DSC, DPC, etc.) may be configured to not execute any of the functional requests of a received initiating message in response to determining that the received message is missing one or more IEs/IE groups with specified criticality "Reject IE." The receiving entity may reject the method/procedure and report the missing IEs/IE groups using the message normally used to report unsuccessful outcome of the method/procedure. When it is determined that the information received in the initiating message was insufficient to determine a value for all IEs that are required to be present in the message used to report the unsuccessful outcome of the method/procedure, the receiving entity may terminate the method/procedure and initiate a DSAAP error indication method/procedure.

[0268] As a further example, when a received message initiating a method/procedure that does not have a message to report unsuccessful outcome is missing one or more IEs/IE groups with specified criticality "Reject IE", the receiving entity may terminate the method/procedure and initiate a DSAAP error indication method/procedure.

[0269] As yet another example, when a received response message is missing one or more IEs/IE groups with specified criticality "Reject IE, the receiving entity may consider the method/procedure as unsuccessfully terminated and initiate a local error handling method/procedure.

[0270] As another example, when a received message initiating a method/procedure is missing one or more IEs/IE groups with specified criticality "Ignore IE and Notify Sender", the receiving entity may ignore that those IEs are missing and continue with the method/procedure based on the other IEs/IE groups present in the message and report in the response message of the method/procedure that one or more IEs/IE groups were missing. When the information received in the initiating message is insufficient to determine a value for all IEs that are required to be present in the response

message, the receiving entity may terminate the method/procedure and initiate a DSAAP error indication method/procedure.

[0271] As another example, when a received message initiating a method/procedure that does not have a message to report the outcome of the method/procedure is missing one or more IEs/IE groups with specified criticality "Ignore IE and Notify Sender", the receiving entity may ignore that those IEs are missing and continue with the method/procedure based on the other IEs/IE groups present in the message and initiate a DSAAP error indication method/procedure to report that one or more IEs/IE groups were missing.

[0272] As another example, when a received message a received response message is missing one or more IEs/IE groups with specified criticality "Ignore IE and Notify Sender", the receiving entity may ignore that those IEs are missing and continue with the method/procedure based on the other IEs/IE groups present in the message and initiate a DSAAP error indication method/procedure to report that one or more IEs/IE groups were missing.

[0273] As another example, when a received message initiating a method/procedure is missing one or more IEs/IE groups with specified criticality "Ignore IE", the receiving entity may ignore that those IEs are missing and continue with the method/procedure based on the other IEs/IE groups present in the message.

[0274] As another example, when a received response message is missing one or more IEs/IE groups with specified criticality "Ignore IE", the receiving entity may ignore that those IEs/IE groups are missing and continue with the method/procedure based on the other IEs/IE groups present in the message.

[0275] The receiving entity (e.g., DSC, DPC, etc.) may be configured to respond to messages that include IEs or IE groups that received in wrong order, include too many occurrences, or are erroneously present (i.e., are included and marked as "conditional" when the condition is not met) in various ways. For example, the receiving entity (e.g., DSC, DPC, etc.) may be configured to not execute any of the functional requests of a received initiating message in response to determining that the received message includes IEs or IE groups in wrong order, includes too many occurrences of an IE, or includes erroneously present IEs. The receiving entity may reject the method/procedure and report the cause value "Abstract Syntax Error (Falsely Constructed Message)" using the message normally used to report unsuccessful outcome of the method/procedure. When the information received in the initiating message is insufficient to determine a value for all IEs that are required to be present in the message used to report the unsuccessful outcome of the method/procedure, the receiving entity may terminate the method/procedure and initiate a DSAAP error indication method/procedure.

[0276] As another example, when a message initiating a method/procedure that does not have a message to report unsuccessful outcome is received containing IEs or IE groups in wrong order or with too many occurrences or erroneously present, the receiving entity may terminate the method/procedure, and initiate a DSAAP error indication method/procedure using the cause value "Abstract Syntax Error (Falsely Constructed Message)".

[0277] As another example, when a response message is received containing IEs or IE groups in wrong order or with too many occurrences or erroneously present, the receiving entity may consider the method/procedure as unsuccessfully terminated and initiate local error handling.

[0278] As mentioned above, protocol errors include transfer syntax errors, abstract syntax errors, and logical errors. A logical error occurs when a message is comprehended correctly, but the information contained within the message is not valid (i.e. semantic error), or describes a method/procedure which is not compatible with the state of the receiving entity.

[0279] In an embodiment, a receiving entity (e.g., DSC, DPC, etc.) may be configured to perform error response operations based on the class of the method/procedure and irrespective of the criticality information of the IE's/IE groups containing the erroneous values in response to determining/detecting an logical error.

[0280] For example, when a logical error is detected in a request message of a class 1 method/procedure, and the method/procedure has a message to report this unsuccessful outcome, this message may be sent with an appropriate cause value (i.e., in the clause IE), such as "semantic error" or "message not compatible with receiver state." When a logical error is detected in a request message of a class 1 method/procedure, and the method/procedure does not have a message to report this unsuccessful outcome, the method/procedure may be terminated and a DSAAP error indication method/procedure may be initiated with an appropriate cause value. Where the logical error exists in a response message of a class 1 procedure, the procedure may be considered as unsuccessfully terminated and local error handling may be initiated.

[0281] When a logical error is detected in a message of a class 2 procedure, the procedure may be terminated and a DSAAP error indication procedure may be initiated with an appropriate cause value.

[0282] In the various embodiments, the receiving entity (e.g., DSC, DPC, etc.) may be configured to perform a local error handling method/procedure (as opposed to a DSAAP error indication method/procedure) when a protocol error is detected in the ERROR INDICATION message. In case a response message or error indication message needs to be returned, but the information necessary to determine the receiver of that message is missing, the procedure may be considered as unsuccessfully terminated and local error handling may be initiated. When an error that terminates a procedure occurs, the returned cause value may reflect the error that caused the termination of the procedure even if one or more abstract syntax errors with criticality "ignore and notify" have earlier occurred within the same procedure.

[0283] FIG. **18** illustrates the operations and information flows between various components when performing a DSA resource update method **1800** in accordance with an embodiment. In the example illustrated in FIG. **18**, the operations of DSA resource update method **1800** are performed by various components, including a wireless device **102**, a first eNodeB **116***a*, a first SGW **118***a*, a first DSC **144***a*, a DPC **146**, a second DSC **144***b*, a second SGW **118***b*, and a second eNodeB **116***b*. The first eNodeB **116***a*, first SGW **118***a*, and first DSC **144***a* are included in a first network (i.e., a lessee network). The second DSC **144***b*, second SGW **118***b*, and second eNodeB **116***b* are included in a second network (i.e., a lessor network).

[0284] In operation **1802**, the wireless device **102** may attach to the lessee network. In operation **1804**, the first eNodeB **116***a* may monitor and report resource usages and node

level congestion levels to the first DSC **114***a*. This may be accomplished by the first eNodeB **116***a* generating and sending a resource update message to the first DSC **144***a*, either directly (e.g., via the Xe interface) or via the first SWG **118***a* (e.g., via the S1-U interface). In an embodiment, the first eNodeB **116***a* may generate the resource update message to include information suitable for reporting resource usage level for multiple cells, including the cell to which the wireless device **102** is attached. In various embodiments, the first eNodeB **116***a* may be configured to send such resource update messages periodically or in response to detecting a condition or event (e.g., new wireless device attached, etc.).

[0285] In operation **1806**, the first SGW **118***a* may use the information included in the received resource update message to update its resource usage records and/or forward the resource update message to the DSC **144***a*. In operation **1808**, the first SGW **118***a* may start a resource update acknowledgment timer. In operation **1810**, the first DSC **144***a*, may generate and send a resource update acknowledgment message to the first eNodeB, either directly or via the first SWG **118***a*. In operation **1812**, the first SGW **118***a* may forward the resource update acknowledgment message to the first eNodeB **116***a* and/or use the information included in the received acknowledgment message to update its resource usage records. In operation **1814**, the first SGW **118***a* may stop the resource update acknowledgment timer in response to receiving the acknowledgment message and/or in response to determining that the resource update acknowledgment message was received prior the expiration of the resource update acknowledgment timer.

[0286] In operations **1816-1822**, the first eNodeB **116***a* may periodically report usage/congestion levels and the first DSC **114***a* and first SGW **118***a* may update their resource usage records, which may be accomplished by performing the same or similar operations as those performed in operations **1804-1814**. Similarly, in operations **1850-1866**, the second eNodeB **116***b*, second DSC **114***b*, and second SGW **118***b* may perform the same or similar operations as those performed as part of operations **1804-1822**.

[0287] In operations **1824** and **1826**, the first DSC **114***a* may determine whether there are excess resources available in the first network for allocation to other networks, and send a resource availability message to the DPC **146**. The resource availability message may include information suitable for informing the DPC **146** of the resources determined to be available for allocation. The DPC **146** may be configured to receive, store, or maintain resource availability information for multiple DSCs and/or for multiple different networks (i.e. different PLMN IDs).

[0288] In operation **1828**, the first DSC **114***a* may start a timer. In operations **1830** and **1832**, the first DSC **114***a* may initiate or participate in an auction by monitoring its available/remaining resources and sending resource availability advertisements to DPC **1830**. In operation **1834**, the first DSC **114***a* may determine that the timer expired, and discontinue advertizing its resources. In operations **1870-1880**, the second DSC **114***b* may perform the same or similar operations as those performed as part of operations **1824-1834**.

[0289] FIG. **19** illustrates an embodiment DSA method **1900** of allocating resources in a first communication network for access and use by a second communication network. The operations of DSA method **1900** may be performed by a processing core of a DPC **146** component.

[0290] In operation **1902**, a DPC **146** component may establish a communication link to a DSC **144***a* in first communication network. In operation **1904**, the DPC **146** may determine whether a telecommunication resource of the first communication network is available for allocation based on information received via the communication link. In an embodiment, the DPC **146** may determine that the telecommunication resource is available for allocation at a future date and time.

[0291] In operation **1906**, the DPC **146** may broadcast a communication signal that includes information suitable for informing a plurality of communication networks that the telecommunication resource is available for allocation via an auction and including an auction start time for the auction. In operation **1908**, the DPC **146** may receive bids from the plurality of communication networks for the telecommunication resource determined to be available for allocation in response to broadcasting the communication message and after the auction start time included in the broadcast communication signal. In an embodiment, receiving bids from the plurality of communication networks may include receiving bids for access and use of the telecommunication resource determined at the future date and time.

[0292] In operation **1910**, the DPC **146** may accept only the bids received from authorized networks determined to be eligible to participate in the auction. For example, the DPC **146** may determine whether the telecommunication resource is compatible with each of the plurality of communication networks, authorize networks in the plurality of communication networks as being eligible to participate in the auction based on their compatibility with the telecommunication resource, and accept bids from only the authorized networks.

[0293] In operation **1912**, the DPC **146** may allocate the telecommunication resource of the first communication network for access and use by a second communication network in the plurality of communication networks based on accepted bids. In an embodiment, allocating the telecommunication resource may include allocating the telecommunication resource of the first communication network for access and use by the second communication network at the future date and time. In operation **1914**, the DPC **146** may send a communication message to the second communication network that includes information suitable for informing the second communication network that use of allocated telecommunication resource may begin. In operation **1916**, the DPC **146** may record a transaction in a transaction database identifying the telecommunication resource as being allocated for use by the second communication network.

[0294] In operation **1918**, the DPC **146** may request return of the allocated telecommunication resource. In operation **1920**, the DPC **146** may broadcast a second communication signal to inform the plurality of communication networks that the telecommunication resource is available for reallocation via a second auction.

[0295] FIG. **20** illustrates another embodiment DSA method **2000** of allocating resources in a first communication network for access and use by a second communication network. The operations of DSA method **2000** may be performed by a processing core of a DPC **146** component.

[0296] In block **2002**, the DPC **146** component may establish a communication link to a DSC **144***a* in first communication network. In block **2004**, the DPC **146** component may determine that a resource in a first communication network is available for allocation. In block **2006**, the DPC **146** compo-

nent may broadcast a first communication signal informing a plurality of communication networks that the resource is available for allocation and of a geographical area associated with the resource. In block **2008**, the DPC **146** component may allocate the resource of the first communication network for access and use by a second communication network in the plurality of communication networks. In block **2010**, the DPC **146** component may broadcast a second communication signal informing the second communication network that use of allocated telecommunication resource may begin in the geographical area. In block **2012**, the DPC **146** component may record a transaction in a transaction database identifying the telecommunication resource as being allocated for use by the second communication network.

[0297] In operation **2014**, the DPC **146** component may request return of the allocated telecommunication resource. In operation **2016**, the DPC **146** may broadcast a second communication signal to inform the plurality of communication networks that the telecommunication resource is available for reallocation via a second auction.

[0298] In an embodiment, the DSA method **2000** may further include the DPC **146** component receiving resource configuration information relating to a resource allocation scheme from a first DSC **144** in the first communication network and sending the resource configuration information to a second DSC **144** in the second communication network. In a further embodiment, the DSA method **2000** may include the DPC **146** component receiving coordination information relating to availability of the telecommunication resource based on geographical areas from the first DSC **144** and sending the coordination configuration information to the second DSC **144**.

[0299] In a further embodiment, the DPC **146** component may be configured to negotiate a resource leasing scheme between the first and second communication networks for a use of the resource, and coordinating a handover of a wireless device between the first and second communication networks based on geographic boundaries defined in the resource leasing scheme. The DPC **146** may be further configured to determine the validity of a subscriber device (e.g., wireless device **102**) of the second communication network based on the proximity of the subscriber device to the geographical area, level of quality of service available to the subscriber device, and/or information included in the resource leasing scheme.

[0300] In various embodiments, the DPC **146** may be configured to instruct the subscriber device to change networks or to establish a communication link to a resource in the first communication network based on the proximity of the subscriber device to the geographical area, level of quality of service available to the subscriber device, and/or terms of the resource leasing scheme. The DPC **146** may be configured to instruct a subscriber device that is actively connected to or using the telecommunication resource to change networks and/or to attach to another resource based on the proximity of the subscriber device to the geographical area.

[0301] As discussed above, the various embodiments may include a PCRF **134** component configured to receive eNodeB congestion state information from the DSC **144** or eNodeB **116**, categorize the wireless devices attached to the eNodeB **116** (and/or another eNodeBs in the same network) into one or more categories (e.g., primary, secondary, "users prone to create congestion," etc.), and perform various congestion response operations based on the categories and/or subcategories to which the devices belong to reduce the congestion at the eNodeB **116**.

[0302] FIG. **21** illustrates a method **2100** of controlling the congestion levels of an eNodeB **116**. Method **2100** may be performed by processing cores of a PCRF **134** component, a PCEF **128** component, an eNodeB **116** component, or a combination thereof.

[0303] In block **2102**, a processing core may monitor user traffic (e.g., call and data traffic, etc.) or congestion of the eNodeB at the RAN level. As part of these operations, the processing core may monitor call volume, resource usage, number of active connections, bandwidth, etc. to determine whether the network activity exceeds a threshold value. In an embodiment, the processing core may monitor user traffic and congestion by receiving congestion state information from a DSC or eNodeBs that identifies a current congestion state (e.g., Normal, Minor, Major, Critical, etc.) of the eNodeB. Each congestion state may be associated with a congestion level. For example, the "Normal" congestion state may indicate that the eNodeB, etc. is operating under normal conditions, the "Minor" congestion state may indicate that the eNodeB is experiencing minor congestion, the "Major" congestion state may indicate that the eNodeB is experiencing significant congestion, and the "Critical" congestion state may indicate that the eNodeB is experiencing severe congestion or an emergency situation.

[0304] In determination block **2104**, the processing core may determine whether the eNodeB is congested. For example, the processing core may determine whether the current congestion state of the eNodeB is Minor, Major, or Critical. In response to determining that the eNodeB is congested (i.e., determination block **2104**="Yes"), in block **2106** the processing core may perform various policy or control operations to implement stricter policy rules and/or coordinate the operations of network components to reduce the congestion level of the eNodeB. For example, the processing core may generate a strict policy rule that prevents new devices from attaching to the eNodeB, and send the generated policy rule to a PCEF **128** for enforcement.

[0305] As further examples, in operation of block **2104**, the processing core may perform various congestion response operations to accomplish various functions, including the stopping or preventing the creation of additional bearers for select devices attached to the eNodeB, stopping or preventing new devices from attaching to the eNodeB, stopping or preventing the upgrading of radio bearers of select devices, handing over select devices to a non-congested eNodeB in the same network as the congested eNodeB based on the device's location, decreasing the bit rates consumed by select devices by modifying the bearers of those devices, deleting the bearers of select devices to free up resources, handing over select devices to a non-congested eNodeB in a different network based on a location of the device and a service level agreement with another network, terminating or dropping select devices (e.g., devices determined to contribute most to the congestion levels of the eNodeB), and other similar operations for mitigating or reducing the congestion level of the eNodeB. The processing core may repeat the operations of blocks **2102** through **2106** until it determines that the eNodeB is no longer congested (i.e., in a "Normal" congestion state).

[0306] In response to determining that the eNodeB is not congested (i.e., determination block **2104**="No"), in block **2108**, the processing core may determine whether the current

policy rules are strict rules aimed at reducing the congestion levels of the eNodeB. In response to determining that the current policy rules are strict rules (i.e., determination block **2108**="Yes"), in block **2110**, the processing core may implement normal or less strict policy rules. For example, in block **2110**, the processing core may generate an updated policy rule that allows (or does not prevent) new devices from attaching to the eNodeB. In response to determining that the current policy rules are not too strict or primarily aimed at reducing the congestion levels the eNodeB (i.e., determination block **2108**="No"), the processing core may continue monitoring the congestion levels of the eNodeB in block **2102**. The operations of blocks **2102-2110** may be performed repeatedly, periodically, continuously, or near-continuously to control/manage the congestion levels of the eNodeB.

[0307] FIG. **22** illustrates a method **2200** for reducing the congestion level of an eNodeB based on categories and/or subcategories in accordance with an embodiment. Method **2200** may be performed by a processing core of a PCRF **134** component.

[0308] In block **2202** of method **2200**, the processing core may receive congestion state information from an eNodeB in its network and determine that the eNodeB is congested. The congestion state information may include an eNodeB congestion state and information identifying the wireless devices that are attached to (or being serviced by) the eNodeB. In block **2204**, the processing core may categorize the identified wireless devices (i.e., devices attached to eNodeB) that are subscribers to its network as primary devices. In an embodiment, the processing core may categorize the wireless devices based on the information received from the eNodeB, such as a device identifier, classification information, usage information, user profile information, etc. In another embodiment, the processing core may be configured to categorize the wireless devices based on information received from other network components (e.g., MME, HSS, etc.).

[0309] Returning to FIG. **22**, in block **2206**, the processing core may categorize the identified wireless devices that subscribe to other networks (i.e., to a lessee network, etc.) as secondary devices. In block **2208**, the processing core may further categorize the primary and secondary devices into subcategories. These subcategories may include "users prone to create congestion", "users with data sensitive applications," and "users with delay sensitive applications." In various embodiments, the processing core may categorize the devices into these and other subcategories based on the data applications used by the devices, user subscription details, user feedback, user profiles, operator policies, etc.

[0310] In block **2210**, the processing core may perform congestion response operations based on the categories and/or subcategories to which the devices belong. By performing the congestion response operations based on the categories and/or subcategories to which the devices belong, the processing core may intelligently reduce or mitigate user traffic and congestion levels of the eNodeB and/or continue to provide adequate service to its higher priority users (i.e., network subscribers, etc.).

[0311] FIG. **23** illustrates various example congestion response operations **2302-2316**, any or all of which may be performed by a processing core of a PCRF **134** component in response to determining that the eNodeB is congested (e.g., as part of block **2210** illustrated in FIG. **22**).

[0312] Specifically, block **2302** of FIG. **23** illustrates that the processing core may stop creating additional bearers for select devices attached to the eNodeB. Alternatively or in addition, the processing core may prevent new devices from attaching to the eNodeB in block **2304**. The processing core may stop or prevent the upgrading radio bearers for select devices in block **2306**. The processing core may handover select devices to a non-congested eNodeB in the same network as the congested eNodeB based on the device's location in block **2308**. The processing core may decrease bit rates consumed by select devices by modifying the bearers of those devices in block **2310**. The processing core may free up the resources by deleting the bearers of select devices in block **2312**. The processing core may handover select devices to a non-congested eNodeB in a different network based on a location of the device and a service level agreement with another network in block **2314**. The processing core may terminate/drop select devices in block **2316**. For example, the processing core may drop devices determined to contribute most to the congestion levels of the eNodeB or devices categorized into the "users prone to create congestion" subcategory in block **2316**.

[0313] In the various embodiments, these and other congestion response operations may be performed based on priorities, categories, and/or subcategories associated with wireless devices. For example, a processing core may be configured to apply the congestion response operations to secondary devices before applying them to primary devices. As such, the processing core may intelligently reduce or mitigate congestion at the eNodeB while continuing to provide adequate service to its higher priority users (i.e., primary devices).

[0314] FIG. **24** illustrates an embodiment congestion response method **2400** for reducing the congestion level of an eNodeB. Method **2400** may be performed by a processing core of a PCRF component. In an embodiment, method **2400** may be performed in response to the PCRF component determining that the eNodeB is congested (i.e., in response to determining that the congestion state of the eNodeB is Minor, Major, or Critical).

[0315] In block **2402**, the processing core may select primary devices, secondary devices, or both. In block **2404**, the processing core may stop or prevent the creation of additional bearers on the congested eNodeB for the selected devices.

[0316] For example, if the processing core selects secondary devices in block **2402**, then processing core may stop or prevent the creation additional bearers by the secondary devices in block **2404**. In an embodiment, as part of block **2404**, the processing core may stop/prevent the creation additional bearers based on priorities or the categories to which the devices belong. For example, when both primary and secondary devices are selected in block **2402**, the processing core may stop the creation of additional bearers for secondary devices before stopping additional bearers for the primary devices in block **2404**.

[0317] If these operations (i.e., preventing creation of additional bearers by secondary devices) do not adequately reduce the congestion levels of the eNodeB, the processing core may perform these or other congestion response operations on the same or different categories of devices. In an embodiment, the processing core may be configured to perform these and other congestion response operations until the congestion state of the eNodeB returns to normal (i.e., until congestion state of the eNodeB is set to "Normal").

[0318] As mentioned above, in block **2404**, the processing core may stop/prevent the creation additional bearers. This

may be accomplished by generating strict policy rules and sending the generated policy rules to a PCEF component for enforcement. The processing core may also stop/prevent the creation additional bearers by rejecting (or causing another component to reject) credit control requests (CCRs) that are associated with the selected devices (i.e., primary devices, secondary devices, or both).

[0319] Returning to FIG. **24**, in block **2406**, the processing core may reject CCRs of the selected devices and/or send failure messages to the devices that request/require further CCRs. In block **2408**, the processing core may receive updated eNodeB congestion state information that indicates that the eNodeB is now operating in the "Normal" congestion state (or a notification message that indicates that eNodeB is no longer congested). In block **2410**, the processing core may start allowing the selected devices to create additional bearers on the eNodeB. This may accomplished by generating and sending updated (i.e., less strict) policy rules to the PCEF component for enforcement, by accepting CCRs from the selected devices, etc.

[0320] FIG. **25** illustrates another embodiment congestion response method **2500** for reducing the congestion level of the eNodeB. Method **2500** may be performed by a processing core of a PCRF **134** component, such as in response to the PCRF determining that the eNodeB is congested.

[0321] In block **2502**, the processing core may select primary devices, secondary devices, or both. In block **2504**, the processing core may prevent new devices from attaching to the congested eNodeB. In an embodiment, this may accomplished by generating strict policy rules and sending the generated policy rules to a PCEF component for enforcement. In block **2506**, the processing core may reject CCR messages that request or require the creation of a new IP-CAN session from the selected devices and/or send failure messages to the devices sending or requesting such CCRs. In block **2508**, the processing core may receive updated eNodeB congestion state information that indicates that the eNodeB is now operating in the "Normal" congestion state (or a notification message that indicates that eNodeB is no longer congested). In block **2510**, the processing core may start allowing the selected devices to attach to the eNodeB. In various embodiments, this may accomplished by generating and sending updated policy rules to the PCEF component for enforcement, accepting CCRs that request or require the creation of a new IP-CAN session from the selected devices, etc.

[0322] FIG. **26** illustrates yet another embodiment congestion response method **2600** for reducing the congestion level of the eNodeB. Method **2600** may be performed by a processing core of a PCRF **134** component in response to determining that the eNodeB is congested (i.e., that the congestion state of the eNodeB is Minor, Major, or Critical).

[0323] In block **2602**, the processing core may select primary devices, secondary devices, or both. In block **2604**, the processing core may further select devices grouped into the "users prone to create congestion" sub-category from the selected devices (i.e., primary devices, secondary devices, or both). For example, if the secondary devices are selected in block **2602**, the processing core may select only the secondary devices that are grouped into the "users prone to create congestion" sub-category. This allows the processing core to first apply the congestion response operations to a focused subset of the all the identified wireless devices, and then to other groups/categories if congestion persists. As such, the processing core may intelligently reduce congestion (e.g., by first limiting devices that most likely to contribute significantly to the network congestion, etc.) and/or better prioritize the access and use of the network resources (e.g., by allowing higher priority users to continue using network resources, etc.).

[0324] In block **2606**, the processing core may stop or prevent upgrading the radio bearers on the eNodeB for the selected devices and/or based on priorities/categories. In block **2608**, the processing core may reject CCR messages that request/require increases in bit rates for existing bearers from the selected devices and/or send failure messages to the devices sending/requesting such CCRs. In block **2610**, the processing core may receive a notification message that indicates that eNodeB is no longer congested (e.g., updated eNodeB congestion state information). In block **2612**, the processing core may start allowing the selected devices to upgrade radio bearers on the eNodeB (e.g., by generating updated policy rules, etc.).

[0325] FIG. **27** illustrates another congestion response method **2700** for reducing the congestion level of the eNodeB. Method **2700** may be performed by a processing core of a PCRF **134** component in response to determining that the eNodeB is congested.

[0326] In block **2702**, the processing core may select primary devices, secondary devices, or both. In block **2704**, the processing core may further select devices grouped into the "users prone to create congestion" sub-category from the selected devices. For example, if the secondary devices are selected in block **2702**, the processing core may select only the secondary devices that are grouped into the "users prone to create congestion" sub-category in block **2704**.

[0327] In block **2706**, the processing core may determine the locations of the selected devices (e.g., secondary devices that are grouped into the "users prone to create congestion" sub-category), identify non-congested target eNodeBs that are in the same network as the congested eNodeB based on the device locations, and identify the selected devices are to be handed over based on the availability and proximity of non-congested target eNodeBs. In block **2708**, the processing core may inform eNodeB that the selected devices are to be handed over to the target eNodeB. In an embodiment, this may accomplished by the PCRF instructing a DSC component to initiate a handed over procedure, which may cause the DSC to inform the congested eNodeB of the devices that are selected for handover and the target eNodeB to which the selected device are to be handed over.

[0328] FIG. **28** illustrates another embodiment congestion response method **2800** for reducing the congestion level of the eNodeB. Method **2800** may be performed by a processing core of a PCRF **134** component in response to determining that the eNodeB is congested.

[0329] In block **2802**, the processing core may select primary devices, secondary devices, or both. In block **2804**, the processing core may further select devices grouped into the "users with delay sensitive applications" and/or "users prone to create congestion" subcategories from the selected devices. For example, the processing core may first select devices grouped into the "users with delay sensitive applications" subcategory, and then select devices grouped "users prone to create congestion" subcategory. The processing core may then perform congestion response operations based on the order in which the devices are selected.

[0330] In block **2806**, the processing core may modify bearers for the selected devices to decrease the bit rates con-

sumed by those devices. In an embodiment, the processing core may modify the bearer based on priorities, categories, or order in which the devices were selected. For example, if the processing core selects secondary devices in block **2802**, the processing core may first modify bearers for secondary devices grouped into the "users with delay sensitive applications" subcategory, then modify bearers for secondary devices grouped into the "users prone to create congestion" subcategory. In block **2808**, the processing core may send a "Re-Auth-Request" command that identifies a reduced bit rate for the bearers of the selected devices to a PGW (which is responsible for filtering downlink user IP packets into the different QoS-based bearers) so that the bearers are modified across the network and/or across multiple network components.

[0331] FIG. **29** illustrates another embodiment congestion response method **2900** for reducing the congestion level of the eNodeB. Method **2900** may be performed by a processing core of a PCRF **134** component in response to determining that the eNodeB is congested.

[0332] In block **2902**, the processing core may select primary devices, secondary devices, or both. In block **2904**, the processing core may further select devices grouped into the "users prone to create congestion" and/or "users with delay sensitive applications" subcategories from the selected devices. For example, the processing core may first select devices grouped into the "users prone to create congestion" subcategory, then select devices grouped into the "users with delay sensitive applications" subcategory. The processing core may then perform congestion response operations based on the order in which the devices are selected.

[0333] In block **2906**, the processing core may delete bearers for the selected devices to free up the resources consumed by those devices. In an embodiment, the processing core may delete the bearer based on priorities, categories, or order in which the devices were selected. For example, if the processing core selects secondary devices in block **2902**, the processing core may delete bearers for secondary devices grouped into the "users prone to create congestion" subcategory before deleting bearers for secondary devices grouped into the users with delay sensitive applications" subcategory. In block **2908**, the processing core may send a "Re-Auth-Request" command to delete the bearers of the selected devices to a PGW so that the bearers are deleted across the network and/or across multiple network components.

[0334] FIG. **30** illustrates another embodiment congestion response method **3000** for reducing the congestion level of the eNodeB. Method **3000** may be performed by a processing core of a PCRF **134** component in response to determining that the eNodeB is congested.

[0335] In block **3002**, the processing core may select primary devices, secondary devices, or both. In block **3004**, the processing core may further select devices grouped into the "users prone to create congestion" and/or "users with delay sensitive applications" subcategories from the selected devices. For example, the processing core may first select devices grouped into the "users prone to create congestion" subcategory, then select devices grouped into the "users with delay sensitive applications" subcategory. In block **3006**, the processing core may begin handing over the selected devices to a non-congested eNodeB in a different network based on the device locations and service level agreement with the other network. In an embodiment, the processing core may begin handing over the devices based on priorities, categories, or order in which the devices were selected. In block **3008**, the processing core may receive target network information from DSC and inform the DSC of the selected devices that are to be handed over so as to cause the DSC to inform the congested eNodeB, the selected devices, and/or the target eNodeB of the handover operations.

[0336] FIG. **31** illustrates another embodiment congestion response method **3100** for reducing the congestion level of the eNodeB. Method **3100** may be performed by a processing core of a PCRF **134** component in response to determining that the eNodeB is congested.

[0337] In block **3102**, the processing core may select primary devices, secondary devices, or both. In block **3104**, the processing core may further select devices grouped into the "users prone to create congestion" subcategory from the selected devices. In block **3106**, the processing core may begin terminating or dropping the selected devices based on priorities, categories, or order in which the devices were selected. In block **3108**, the processing core may send "Re-Auth-Request" command to delete the sessions of the selected users to PGW.

[0338] The various embodiments may include or use a dynamic spectrum arbitrage application part (DSAAP) protocol and/or component that is configured to allow, facilitate, support, or augment communications between two or more DSA components (e.g., DPC, DSC, eNodeB, MME, HSS, etc.) so as to improve the efficiency and speed of the DSA system. A DSA component may be any component discussed in this application and/or any component that participates in any of the DSA operations, communications, or methods discussed in this application. As such, the DSAAP component(s) may be configured to allow, facilitate, support, or augment communications between any of the components discussed in this application, including the communications between a DPC component and a DSC component, between the DSC component and a eNodeB component, between the DSC component and an MME component, between the DSC component and an HSS component, between the MME component and the HSS component, between the eNodeB component and a wireless device, etc.

[0339] To facilitate the communications between two or more DSA components, the DSAAP component(s) may publish application programming interfaces (API) and/or include client modules that facilitate communications between the DSA components. In addition, the DSAAP component(s) may be configured to allow the DSA components to communicate specific information, use specific communication messages, and/or perform specific operations that together provide various DSA functions that further improve the efficiency and speed of the DSA system and participating networks.

[0340] As an example, the DSAAP component(s) may be configured to allow an eNodeB to communicate with a DSC component (e.g., via the Xe interface), with other eNodeBs (e.g., via an X2 interface), and with various other components (e.g., via the S1 interface). As a further example, the DSAAP component(s) may be configured to allow, facilitate, support, or augment communications between the DSC component and the DPC component so as to allow the DPC and/or DSC components to better pool resources across the different networks, better monitor traffic and resource usage in the various networks, to more efficiently communicate bids and bidding information, to quickly and efficiently register and deregister components, and better perform backoff operations. The

DSAAP component(s) may also improve the DSA resource auctioning operations by improving the performance and efficiency of the procedures for bidding, generating invoices, advertizing resources, requesting resources, purchasing resources, validating bid credentials, etc.

[0341] In the various embodiments, all or portions of the DSAAP component may be included in one or more DSA components, such as a DPC component, a DSC component, an eNodeB component, an MME component, and an HSS component. The DSAAP component may be implemented in hardware, software, or a combination of hardware and software. In an embodiment, the DSAAP component may be configured to implement a DSAAP protocol, which may be defined over the Xe, Xd, and/or X2 reference points. In various embodiments, the Xe reference point between DSC and eNodeB may use the DSAAP protocol, TR-069 protocol, and/or TR-192 data model extensions to support listing available resources at the eNodeB and notifying the eNodeB of bid/buy confirmations. The Xd reference point between DSC and DPC may use the DSAAP protocol for dynamic spectrum and resource arbitrage operations. The X2 interface/reference point between the eNodeBs may also use the DSAAP protocol to communicate information.

[0342] In various embodiments, the DSAAP component(s) may be configured to allow the various DSA components (e.g., DSC, DPC, eNodeB, etc.) to communicate using the DSAAP protocol and/or to perform various DSAAP methods. DSAAP methods may be performed in any of the DSA systems discussed in this application, such as a system that includes a first DSC server in a first telecommunication network (e.g., a lessee network), a second DSC server in second telecommunication network (e.g., a lessor network), and a DPC server that is outside of the first and second telecommunication networks.

[0343] The various embodiments may be implemented on a variety of mobile wireless computing devices, an example of which is illustrated in FIG. **32**. Specifically, FIG. **32** is a system block diagram of a mobile transceiver device in the form of a smartphone/cell phone **3200** suitable for use with any of the embodiments. The cell phone **3200** may include a processor **3201** coupled to internal memory **3202**, a display **3203**, and to a speaker **3204**. Additionally, the cell phone **3200** may include an antenna **3205** for sending and receiving electromagnetic radiation that may be connected to a wireless data link and/or cellular telephone transceiver **3206** coupled to the processor **3201**. Cell phones **3200** typically also include menu selection buttons or rocker switches **3207** for receiving user inputs.

[0344] A typical cell phone **3200** also includes a sound encoding/decoding (CODEC) circuit **3208** which digitizes sound received from a microphone into data packets suitable for wireless transmission and decodes received sound data packets to generate analog signals that are provided to the speaker **3204** to generate sound. Also, one or more of the processor **3201**, wireless transceiver **3206** and CODEC **3208** may include a digital signal processor (DSP) circuit (not shown separately). The cell phone **3200** may further include a ZigBee transceiver (i.e., an IEEE 802.15.4 transceiver) for low-power short-range communications between wireless devices, or other similar communication circuitry (e.g., circuitry implementing the Bluetooth® or WiFi protocols, etc.).

[0345] The embodiments described above, including the spectrum arbitrage functions, may be implemented within a broadcast system on any of a variety of commercially available server devices, such as the server **3300** illustrated in FIG. **33**. Such a server **3300** typically includes a processor **3301** coupled to volatile memory **3302** and a large capacity nonvolatile memory, such as a disk drive **3303**. The server **3300** may also include a floppy disc drive, compact disc (CD) or DVD disc drive **3304** coupled to the processor **3301**. The server **3300** may also include network access ports **3305** coupled to the processor **3301** for establishing data connections with a network **3306**, such as a local area network coupled to other communication system computers and servers.

[0346] The processors **3201**, **3301**, may be any programmable microprocessor, microcomputer or multiple processor chip or chips that can be configured by software instructions (applications) to perform a variety of functions, including the functions of the various embodiments described below. In some wireless devices, multiple processors **3301** may be provided, such as one processor dedicated to wireless communication functions and one processor dedicated to running other applications. Typically, software applications may be stored in the internal memory **3202**, **3302**, before they are accessed and loaded into the processor **3201**, **3301**. The processor **3201**, **3301** may include internal memory sufficient to store the application software instructions. In some servers, the processor **3301** may include internal memory sufficient to store the application software instructions. In some receiver devices, the secure memory may be in a separate memory chip coupled to the processor **3201**. The internal memory **3202**, **3302** may be a volatile or nonvolatile memory, such as flash memory, or a mixture of both. For the purposes of this description, a general reference to memory refers to all memory accessible by the processor **3201**, **3301**, including internal memory **3202**, **3302**, removable memory plugged into the device, and memory within the processor **3201**, **3301** itself.

[0347] The foregoing method descriptions and the process flow diagrams are provided merely as illustrative examples and are not intended to require or imply that the steps of the various embodiments must be performed in the order presented. As will be appreciated by one of skill in the art the order of steps in the foregoing embodiments may be performed in any order. Words such as "thereafter," "then," "next," etc. are not intended to limit the order of the steps; these words are simply used to guide the reader through the description of the methods. Further, any reference to claim elements in the singular, for example, using the articles "a," "an" or "the" is not to be construed as limiting the element to the singular.

[0348] The various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

[0349] The hardware used to implement the various illustrative logics, logical blocks, modules, and circuits described

in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DPC), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but, in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine A processor may also be implemented as a combination of computing devices, e.g., a combination of a DPC and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DPC core, or any other such configuration. Alternatively, some steps or methods may be performed by circuitry that is specific to a given function.

[0350] In one or more exemplary aspects, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored as one or more instructions or code on a non-transitory computer-readable medium or non-transitory processor-readable medium. The steps of a method or algorithm disclosed herein may be embodied in a processor-executable software module which may reside on a non-transitory computer-readable or processor-readable storage medium. Non-transitory computer-readable or processor-readable storage media may be any storage media that may be accessed by a computer or a processor. By way of example but not limitation, such non-transitory computer-readable or processor-readable media may include RAM, ROM, EEPROM, FLASH memory, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above are also included within the scope of non-transitory computer-readable and processor-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and/or instructions on a non-transitory processor-readable medium and/or computer-readable medium, which may be incorporated into a computer program product.

[0351] The preceding description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the following claims and the principles and novel features disclosed herein.

What is claimed is:

1. A method of reducing congestion of an eNodeB in a policy and charging rules function (PCRF) server, the method comprising:

receiving, in a processor of the PCRF server, eNodeB congestion state information and information identifying wireless devices attached to the eNodeB;

categorizing each of the identified wireless devices into a category selected from a plurality of categories, the plurality of categories including primary device category and a secondary device category;

selecting a subset of the identified wireless devices based on the category into which they are categorized; and

performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB.

2. The method of claim **1**, wherein performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises:

preventing new devices from attaching to the eNodeB.

3. The method of claim **1**, wherein performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises:

preventing the creation of additional bearers by the selected wireless devices.

4. The method of claim **1**, further comprising categorizing the identified devices into one or more subcategories, wherein selecting the subset of the identified wireless devices further comprises selecting the subset of wireless devices based on the category and the one or more subcategories into which they are categorized.

5. The method of claim **4**, wherein categorizing the identified devices into one or more subcategories comprises:

determining whether any of the identified wireless devices are prone to create congestion;

determining whether any of the identified wireless devices include data sensitive applications; and

determining whether any of the identified wireless devices include delay sensitive applications.

6. The method of claim **4**, wherein performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises:

preventing radio bearer upgrades on the eNodeB for the selected wireless devices.

7. The method of claim **4**, wherein performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises:

determining a location of a selected device;

identifying a non-congested target eNodeB based on the determined location; and

performing handover operations to hand over the selected device to the non-congested target eNodeB.

8. The method of claim **4**, wherein performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises modifying bearers for the selected devices so as to decrease bit rates consumed by the selected devices.

9. The method of claim **4**, wherein performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises deleting bearers for the selected devices so as to free up resources consumed by the selected devices.

10. The method of claim **4**, wherein performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises performing handover operations to hand over the selected devices to a non-congested target eNodeB in a different network than the PCRF.

11. The method of claim **4**, wherein performing congestion response operations on the selected wireless devices so as to

reduce the congestion of the eNodeB comprises causing the eNodeB to drop the selected devices.

12. The method of claim **1**, further comprising:

determining in a dynamic spectrum policy controller (DPC) server an amount of radio frequency (RF) spectrum resources available for allocation within a first communication network that includes the PCRF server and eNodeB by communicating with a first dynamic spectrum controller (DSC) server in the first communication network;

allocating by the DPC server a portion of available RF spectrum resources of the first communication network for access and use by wireless devices of a second communication network; and

informing the second communication network that use of allocated RF spectrum resources may begin by communicating with a second DSC server in the second communication network.

13. The method of claim **12**, wherein categorizing each of the identified wireless devices comprises categorizing the wireless devices of the second communication network into the secondary device category.

14. The method of claim **1**, further comprising:

monitoring network resource usage in an eNodeB processor of the eNodeB;

determining in the eNodeB processor whether the usage of network resources exceeds a threshold value; and

restricting originations of new sessions of wireless devices attached to the eNodeB and restricting handins of additional wireless devices to the eNodeB in response to determining that the usage of network resources exceeds the threshold value.

15. The method of claim **14**, further comprising classifying the wireless devices attached to the eNodeB into priority groups by the eNodeB processor, wherein restricting originations of new sessions of the wireless devices attached to the eNodeB comprises restricting originations of new sessions of the wireless devices based on the priority groups.

16. The method of claim **15**, further comprising sending by the eNodeB processor the eNodeB congestion state information and information identifying wireless devices attached to the eNodeB in response to determining that the wireless devices attached to the eNodeB belong to the same priority group.

17. A policy and charging rules function (PCRF) server, comprising:

a processor is configured with processor-executable instructions to perform operations comprising:

receiving eNodeB congestion state information and information identifying wireless devices attached to an eNodeB;

categorizing each of the identified wireless devices into a category selected from a plurality of categories, the plurality of categories including primary device category and a secondary device category;

selecting a subset of the identified wireless devices based on the category into which they are categorized; and

performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB.

18. The PCRF server of claim **17**, wherein the processor is configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises:

preventing new devices from attaching to the eNodeB.

19. The PCRF server of claim **17**, wherein the processor is configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises:

preventing the creation additional bearers by the selected wireless devices.

20. The PCRF server of claim **17**, the processor is configured with processor-executable instructions to perform operations further comprising categorizing the identified devices into one or more subcategories, wherein selecting the subset of the identified wireless devices further comprises selecting the subset of wireless devices based on the category and the one or more subcategories into which they are categorized.

21. The PCRF server of claim **20**, wherein the processor is configured with processor-executable instructions to perform operations such that categorizing the identified devices into one or more subcategories comprises:

determining whether any of the identified wireless devices are prone to create congestion;

determining whether any of the identified wireless devices include data sensitive applications; and

determining whether any of the identified wireless devices include delay sensitive applications.

22. The PCRF server of claim **20**, wherein the processor is configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises:

preventing radio bearer upgrades on the eNodeB for the selected wireless devices.

23. The PCRF server of claim **20**, wherein the processor is configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises:

determining a location of a selected device;

identifying a non-congested target eNodeB based on the determined location; and

performing handover operations to hand over the selected device to the non-congested target eNodeB.

24. The PCRF server of claim **20**, wherein the processor is configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises modifying bearers for the selected devices so as to decrease bit rates consumed by the selected devices.

25. The PCRF server of claim **20**, wherein the processor is configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises deleting bearers for the selected devices so as to free up resources consumed by the selected devices.

26. The PCRF server of claim **20**, wherein the processor is configured with processor-executable instructions to perform operations such that performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises performing handover

operations to hand over the selected devices to a non-congested target eNodeB in a different network than the PCRF.

27. The PCRF server of claim **20**, wherein performing the processor is configured with processor-executable instructions to perform operations such that congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB comprises causing the eNodeB to drop the selected devices.

28. A system, comprising:

an eNodeB; and

a policy and charging rules function (PCRF) server comprising a PCRF processor coupled to the eNode via a communication link,

wherein the PCRF processor is configured with processor-executable instructions to perform operations comprising:

receiving eNodeB congestion state information and information identifying wireless devices attached to the eNodeB from the eNodeB;

categorizing each of the identified wireless devices into a category selected from a plurality of categories, the plurality of categories including primary device category and a secondary device category;

selecting a subset of the identified wireless devices based on the category into which they are categorized; and

performing congestion response operations on the selected wireless devices so as to reduce the congestion of the eNodeB.

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